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PANERO RESEARCH

GUY B. PANERO INC.

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SHELTER CONFIGURATION FACTORS
(Engineering and Cost Analyses)

Contract Number OCD-OS-62-108
Sub-Task 1152B

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FOREWORD

This report summarizes a study effort undertaken by the Special Projects Staff of Guy B. Panero Inc. of New York for the Department of Defense, Office of Civil Defense, to investigate and evaluate those factors which influence the design of below-ground protective structures. The specific aim of the overall project was to identify those configurations which offer the best compromise for use in planning new shelter construction.

Many of the criteria used in analyzing or evaluating factors affecting shelter configuration have been generalized. This was necessary due to the breadth and complexity of subject matter and, partially, due to the unavailability of inputs from concurrent research efforts. While only a broad treatment can be expected in such a case, we do not feel that results evolving from such generalization will be overly sensitive to changes in requirements.

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SUMMARY

This report was prepared for the purpose of identifying shelter shapes and sizes that appear to offer the best compromise for standardizing new shelter design. The study had the following general conditions and criteria:

1 - Below-ground, single-unit structures with a minimum of three feet of earth cover such as might be constructed under parks or playgrounds. This will result in radiation protection factors of 1000 or more.

2 - Consideration of both fallout and blast shelters. Fallout shelters to be designed on a "nominal live-load" * basis and blast shelters to be designed at 35 and 60 psi overpressure.

3 - An extended shelter occupancy time and a closure capability of up to 24 hours.

4 - Protection against the induction of chemical, biological and radiological contaminants.

5 - Single-unit capacities of 100, 500 and 1000 persons each with a 5-minute loading capability.

Other items such as inside and outside environmental conditions, soil conditions, heat loads, habitability needs and access and loading were selected in a general way and/or according to current OCD practice.

The basic structures considered for study were: semicircular reinforced concrete and corrugated steel arches, reinforced concrete domes (hemispheres) and "conventional" steel and concrete rectangular structures. Each shape was analyzed and evaluated in terms of structural requirements, utilization of space, heat transfer to soil and cost. Side investigations were conducted in the categories of environmental control systems and entrances to the extent that these items influenced shelter configuration.

* These structures are designed for fallout only with a nominal live-load surcharge of 300 pounds per square foot, such as might be delivered to a structure under a playground or park.

In summary, the significant findings of this effort are:

1 - Single-level, rectangular fallout shelters designed to accomodate 4-high tiering of bunks will result in minimum cost, regardless of capacity. Calculated physical and installed cost data for such structures and protected entrances only, are as follows:

Capacity	Size	Area/Person	Cost/Sq.Ft.	Cost/Person *
100-persons	25'-4" x 32'-0"	8.1 sq. ft.	$ 9.30	$ 75
500-persons	63'-4" x 62'-0"	7.9 sq. ft.	4.90	39
1000-persons	88'-8" x 84'-0"	7.5 sq. ft.	4.70	35

2 - Large fallout shelters (500-1000 persons) appear to be about half the per-capita cost of small (100-person) fallout shelters.

3 - Large rectangular structures appear to be optimum for use as 35 psi blast shelters and probably as 60 psi blast shelters. Our estimates show cost differentials between optimum fallout and blast structures as follows:

Fallout Shelter	$ 35/person*
35 psi Blast Shelter	51/person
60 psi Blast Shelter	81/person

In addition, our calculations indicate that the blast protection inherent in the rectangular fallout shelters is about 5 psi. The protection inherent in steel and concrete arch and concrete dome fallout shelters is about 35psi.

4 - High-quality (CBR protected) environmental control systems may cost as much as (or more than) the basic fallout shelter structure. Among the three systems studied— outside-air cooled, well-water cooled and refrigerant cooled, well-water cooled systems are lowest in cost and highest in performance. Costwise, the optimum location for environmental control equipment appears to be within the shelter proper rather than in or alongside the entrance unit. Calculated

*These are basic structure and entrance costs and do not include contractors' profit, overhead or contingencies and are based on nationwide averages.

costs for environmental control equipment for 1000-person shelters based on 2 units per shelter(2-500-person packages) are approximately as follows:

Outside-air cooled	\$ 46/person
Well-water cooled	31/person
Refrigerant cooled	42/person

5 - The quantity of internally generated heat dissipated through the shelter walls over a period of 14 days does not appear significant either absolutely or in its effect on the choice of shelter configuration.

6 - The choice of shelter configuration may be highly influenced by a 24-hour closure requirement because of the heat dissipation problem. If a shelter does not have an adequate protected well-water supply (or other heat sink) and must rely on soil mass for the rejection of internally generated heat during closure, then the configuration must be minimum in cross-section and the soil conditions must be ideal or else survivability may become marginal. Under the best conditions, this may result in doubling the cost of the (otherwise) optimum fallout shelter.

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INTRODUCTION

1.1 APPROACH

There is general agreement, today, among civil defense planners that providing protection over a wide range of attack situations may involve a major shelter construction program. To the extent that this is true, it appears desirable to develop design procedures which will give some assurance of maximum performance per new shelter dollar.

One way this might be accomplished is to have a limited number of shelter designs such that the overall program would realize all the benefits inherent in standardization. This is not a new concept. At least one study (1)* indicates that significant savings are possible through mass procurement and construction techniques. The difficulty one may have in using the results of such investigations is that the basic yardsticks for design varied. Some designs were ample, others were austere. This is not a criticism of past shelter projects, but possibly an indication that shelter standardization is not obviously available from specialized solutions. If there is a valid criticism, it probably comes from the designer who wants consistent results but complains that the ground rules keep changing.

In this sense, we have a problem in identifying optimum configurations. We will be examining different structural shapes and sizes with different price tags and performance characteristics. If we do not have a reasonable basis for evaluating these differences we may not be able to draw some useful conclusions. We have attempted to include this in our approach - that is, to consider as many performance requirements as possible in the study effort and to do it in a reasonable manner.

1.2 SCOPE OF WORK

This study was conducted in accordance with Article I -

* See page 196 for references.

Scope of Work, Contract No. OCD-OS-62-108 which, in part, reads as follows:

"The Contractor, - shall perform a study considering all of the factors affecting shelter configurations such as volume to floor ratio, headroom for tiering of bunks, ventilation, heat transfer to soil surface, resistance to blast, economy of construction and similar factors, and to identify those configurations and sizes that appear to offer the best compromise for the purposes of standardization of sizes and shapes of new shelter design, particularly those that will be constructed independent of conventional buildings".

1.3 OBJECTIVES

This study had several specific objectives. Among these were:

1 - To determine structural features for various below-ground building shapes over a range of overpressure criteria.

2 - To uncover any space utilization differences attributable to shape and size.

3 - To investigate and assemble environmental control systems and evaluate the interaction between such utilities and heat transfer to the surrounding soil.

4 - To rate the various configurations in terms of allowable "button-up" time.

5 - To estimate costs and cost differences resulting from performance peculiarities.

1.4 LIMITATIONS

The basic limitation of the overall study in that it is not comprehensive. This effort is one of many concurrent projects devoted to specific areas of shelter research. The results of some of these projects will undoubtedly influence the analysis found herein. Beyond this general qualification, we have the following limitations:

1 - The study considers only below-ground structures such as might be constructed beneath playgrounds, parks, parking areas and other similar real estate.

2 - Multiple units or shelter complexes have not been included.

3 - Construction and equipment cost data are general in nature and have been included mainly for comparison purposes. This information is based on national averages; does not reflect mass-purchasing advantages; and does not include overhead, profit, contingencies and administrative costs.

4.- Design calculations are based on "nation-wide average" conditions of soil, ground water, psychrometrics and other environmental factors.

SECTION 2

PERFORMANCE CRITERIA

2.1 PROTECTION CRITERIA

Protection from the effects of nuclear and chemical and biological weapons usually implies some form of continuous confinement for the entire population. This is a widely accepted countermeasure which has evolved from the basic nature of such weapons and their delivery systems. Although protection criteria will vary widely depending on the weapon system, most civil defense planners have some general agreements concerning the threat. First, the use of such weapons will result (either intentionally or unintentionally) in the creation of environments hostile to man. Second, all but the very quick weapons effects tend to become indiscriminate. Third, these effects decay or become controllable in time.

The object of the countermeasure system (confinement) is to place the population in a more hospitable environment and sustain it until the outside conditions become acceptable. The place of confinement should be so designed that the occupants will be able to emerge without serious after-effects. That is, the designer must recognize that the shelterees may face a hard recovery phase and take this into account in the selection of protective criteria.

The weapons effects which interest shelter planners most are residual radiation, blast overpressure, mass-fire and air contamination. The extent to which these are included in a design determines the quality of a shelter system. Information is available across the entire spectrum of protection from minimum fallout shelters to very high quality, deep underground complexes.(2) The amount of protection provided will depend upon the selected threat, cost and performance factors. In this study, criteria have been selected to account for all of the above effects. In addition, variations in these have been introduced as time and scope allowed.

2.1.1. RADIATION PROTECTION

Most nuclear detonations will result in radiation hazards due to immediate release of radioactive particles and fission product decay. The extent of the hazard depends upon many factors

such as the number, size, type and efficiency of the weapons detonated, the locations of the ground zeros, and the atmospheric conditions.

The radiation hazard with which we are mainly concerned is residual radiation resulting from the wide dispersal of fission products after surface detonations. We are less concerned with prompt radiation effects (especially for high-yield weapons) since other effects such as blast and heat are normally overriding factors.

The amount of protection which should be provided is mainly a function of the density and activity of the fallout field, and the decay scheme which might be expected* and the maximum allowable body burden. For the purposes of this study, we have selected a fallout field of one kiloton of fission products per square mile and a decay scheme based upon past studies by the Naval Radiological Defense Laboratory (USNRDL-TR-247). (3) The fallout history is shown in Table 2.1. The calculations are taken at 3 feet above an infinite fallout plane.

Protection itself may be defined in terms of shelter protection factors and time. If we select a confinement period of several days, we may then be faced with the problem of attenuating a total dose of some 10,000 roentgens to some reasonable level. In determining this level, we must make some allowance for expected dosage after confinement since by and large radiation effects are considered cumulative.

Many studies have placed the maximum permissible long-term dose at about 200 roentgens. If decontamination and/or evacuation procedures are not considered, and if the hazard is as serious as shown on Table 2.1, then even with full attenuation the confinement period could be very long. Under such conditions, post-shelter recovery becomes an integral part of an overall defense system. This does not mean that we can make shelter and post-shelter dose

* Note: From the civil defense point of view this decay scheme should include reasonable estimates of what is possible in terms of decontamination procedures since radiation levels encountered in the post-shelter or recovery phase have a direct bearing on the selection of protective criteria.

TABLE 2.1

Gamma Dose Rates and Integrated Doses for Uniform Contamination Level of 1 Kiloton of Fission Products Per Square Mile.

(NRDL-TR-247)

Time after Detonation	Dose Rate (R/Hr.)	Integrated Dose From 1 hour (Roentgens)
1 hour	3630	0
2 hours	1530	2375
6 hours	342	5082
12 hours	153	6426
24 hours	59	7573
48 hours	21.6	8427
3 days	12.4	8816
1 week	4.9	9537
2 weeks	2.4	10106
1 month	.97	10690
2 months	.36	11121
6 months	.09	11610
1 year	.015	11784
10 years	5.2×10^{-4}	11882
100 years	9.9×10^{-5}	12078

allotments. In fact such assignments may not be useful at all. Being aware of this particular problem we recognize that within our scope of work, minimum exposure is desirable.

This investigation is concerned with below-ground structures. The attenuation or protection factor ratings of such shelters depends upon their average depth of cover (somewhat determined by shape) and size. (5) Without additional cover, normal design procedures will result in different protection ratings among the various configurations. These vary from less than 100 for a concrete rectangular structure, to nearly 1000 for a concrete dome. In terms of acceptable exposure and what is possible in radiation levels, this may mean the difference between low-and high-quality protection. Such differences were not considered in this effort for two reasons: First, because underground shelters and low quality protection are incongruous; and second, because we wish to avoid cost comparing low- and high-quality protection.

To avoid such differences it seemed reasonable to increase protection ratings for all the configurations to the point where exposure becomes negligible. For an accumulated outside dose of 10,000 R, this is in the order of 1000 or more which results in total doses of less than 10 roentgens. For all combinations of shelter sizes and shapes chosen, 3 feet of earth cover will afford such results.

2.1.2. BLAST PROTECTION

Structures designed for below-ground installation, by their nature, have some inherent blast protection. In fact, shelter designers have found it almost impossible—to design a "0 psi" below-ground shelter. Beyond such "built-in" protection the selection of an overpressure criterion is probably the most serious problem facing the shelter designer. Essentially, this is an irrevocable decision. After the shelter has been constructed, it probably cannot be upgraded* at a later date. To the extent that this is true, blast criteria must be selected in accordance with the possible threats over the system's lifetime.

* at least at a reasonable cost.

One of the purposes of this study is to determine cost variations over a range of blast protection. We have chosen to measure blast performance only in terms of static overpressure (psi levels), realizing that such ratings alone are insufficient in determining protection values. A wealth of information on specific weapons effects(4), target analysis, attack gaming and the like is currently available and is recommended to those desiring to evaluate blast protection.

The protection range agreed upon for this study is covered by three points; nominal, 35 psi and 60 psi. The nominal psi level is the inherent protection and for some structures may be 35 psi or more. The other two levels were given to the study group by the project monitor as two points of particular interest to OCD. For any level, appurtenant items such as entries, exits, air intakes and exhausts should be compatible with the rating of the structure.

2.1.3 MASS-FIRE PROTECTION

There appears to be a trend among designers to include features which will allow shelter to function without reliance on outside air for part of the confinement period. (1,6) Generally, this "button-up" capability is thought of as a countermeasure against mass-fire storms. It may also be thought of as a countermeasure against mass contamination, either deliberate or accidental. In any case, independence from outside connections is a high quality feature.

Various lengths of time are used for the closure period. Some planners feel it should not be less than a day, others believe that shorter periods are more reasonable. It is all a matter of cost. From the utility point of view, the technology is available to provide survivable environments for any time period. For our purposes, we shall consider closure periods of up to 24 hours and, in addition, calculate closure capabilities for the several configurations.

2.1.4 CBR CONTAMINANT PROTECTION

Protection from contamination of the shelter environment by chemical, biological and radiological airborne particles can involve the use of high efficiency filtration systems (CBR Filters).

Although much work has been done in this field, (6) absolute requirements have not been established.

It is difficult to determine filtration criteria even for fallout particles. There is some indication that if the air velocity entering the shelter is low enough, very few particles will be inducted. There are other indications that high performance shelters may be degraded by ingestion of even small amounts of material. For chemical and biological agents criteria selection is more difficult.

Lacking specific information across the entire spectrum of filtration requirements, there is a vast cost difference between shelters without filtration systems and those with this feature. CBR filters are costly (7) and their resistance to air flow increases power requirements. (8) It can be shown that shelters with CBR filters are difficult to manually ventilate. (9)

At the outset of this study it appeared that the filtration requirement would have an influence on mechanical-electrical packages and therefore perhaps on the various configureations. As such, this requirement has been included in accordance with U. S. Army Chemical Corps data. (7,8)

2.2 OPERATIONAL CRITERIA

Beyond identifying and evaluating underground structural shapes to meet the selected protective criteria, thereare other factors which may influence the choice of optimum configurations. Among such factors are size or capacity, time of occupancy, environmental conditions, access and space requirements. Even though we are not directly concerned in analyzing such factors, we must include them as basic criteria in a reasonable way. This is apparent for two reasons: First, for contemporary reasons, that is, to make the overall study recognizable or comparible in terms of present planning;and secondly, as insurance against neglecting the "small" parameter which turns out to have a large effect.

Since this is not an overall shelter study, the following operational criteria are general in nature. They are based largely on average conditions and on data derived from previous work in this field.

2.2.1 DESIGN CAPACITIES

At the outset of this effort, one of the problems facing the study group was the selection of shelter sizes. It was apparent that if this study was to have useful results a range of capacities should be chosen to cover the spectrum of requirements of an overall shelter program and to show the cost and performance differences between large and small shelters. Although an attempt was made to do this, it should be remembered that a detailed investigation of optimum shelter capacities is beyond the scope of this study.

There are many factors which influence the choice of shelter capacity. Among these are population density and mobility, alert or warning times, availability of real estate, and construction peculiarities. Given these factors, it is possible (with rather extensive analysis) to develop overall shelter programs for particular areas. Studies have been completed along these lines. One, undertaken as a population mobility study for the Washington, D.C. area, (10) resulted in shelter sizes ranging from 650 to 8900 persons. Another, more specific study by Civil Defense people of Livermore, California, (11) used shelter complexes of 3,000-person capacity made up of shelter "units" of 200- to 400-person capacity. Generally, the previous work on community shelter sizing is in the range of 100 to 10,000 persons. (12)

For the purposes of this study, the 100-person shelter was selected as the "small" shelter unit. At the upper end of the spectrum we have chosen a capacity of 1000 persons. Although there is the possibility that larger units will result in significantly lower per-capita costs, it appeared that single shelter units with capacity ratings much beyond this figure (e.g. by a factor of 10) may not be realistic for the following reasons: First, there is a management problem. Various simulated and paper occupancy studies have attempted to define optimum shelter sizes in terms of managerial limitations. (13,14,15,16) Although the results vary, none of these studies have included or could be extrapolated to include shelter units much in excess of 1000 persons. In addition, if our capacity range is too wide, we may inadvertantly include serious performance differences which may offset some apparent cost gains of large over small configurations. Second, we have a space problem in terms of available sites for the construction of below-ground units. At a nominal area of 10 square feet per person, the

minimum size for a 10,000-person single-level structure is about 320 feet square. Including allowance for construction, this could be as much as 400 feet square which is more than a city* block. Third, we may not be able to use general space criteria. That is, a 10,000-person shelter probably cannot be designed as an enlarged 100-person shelter because of problem compounding.

In summary, the selected unit capacity range is 100 to 1000 persons. This range is covered by these points plus, an intermediate size arbitrarily chosen at 500 persons.

2.2.2 OCCUPANCY TIME

Actual shelter occupancy time will depend on the hostility of the outside environment and the shelter's capability in detecting changes in it. As indicated previously, this period could be several days long. It might be much shorter. In this study, we are required to select an occupancy time only as a means of rating heat dissipation characteristics of the various configurations to the surrounding soil. The period selected is 14 days.

Heat transfer calculations for this period and for "button-up" or closure periods are based, in part, on the assumption that at time equals zero (shelter entry time) the shelter temperature is equal to the surrounding soil temperature.

2.2.3 ENVIRONMENTAL CONDITIONS

The major environmental factors for concern within a shelter are psychrometric conditions, oxygen content, carbon dioxide content, carbon monoxide content and radiation level. Other items of somewhat lesser importance include odors, smoke, dust and "ordinary" chemical irritants. In addition, the list of major factors may be extended to include chemical, biological and radiological warfare agents.

Physiological studies (6,8,17,18,19) have indicated that

* Reference is made to the city block since large shelters are associated with high population densities.

concentrations of O_2 and CO_2 in shelter environments should be limited to not less than 17% and not more than 3% by volume, respectively. These studies also indicate that the O_2 limit is not as critical as the CO_2 limit in terms of damaging pathological changes. Assuming 0.90 cubic foot per hour per person of oxygen consumption and 0.75 cubic foot per hour per person of carbon dioxide production, the time of safe occupancy for unventilated spaces may be roughly calculated as follows:

$$T = 0.04\ V/N$$

where:
- T = Time after entry, hours
- V = Shelter volume, cubic feet
- N = Number of shelterees

The minimum outside air ventilating rate required to maintain 3% CO_2 & 17% O_2 over long time periods is approximately 0.4 cubic foot per minute per person. Most designers prefer to use 1 cfm per person which corresponds to a terminal concentration of 1.4% CO_2. Civil Defense literature (20) recommends 3 cfm per person which will maintain CO_2 at about 0.5%.

Reference to carbon monoxide toxicity levels are numerous. Maximum allowable levels are usually taken at between 100 and 150 ppm. Mild headaches will occur at 200 ppm and survival is improbable at 1500 ppm. (6) In a ventilated shelter this gas would not ordinarily establish cause for concern. However, in shelters with "button-up" capabilities it seems advisable to include monitoring equipment not only for CO but also for CO_2 and O_2.

Most engineers involved in environmental systems design prefer to use effective temperature (E.T.) as a yardstick for measuring psychrometric comfort and this has been extended to measure survivability. Effective temperature (much akin to temperature-humidity index, THI), is an empirical sensory index which attempts to relate combinations of dry-bulb temperature, wet-bulb temperature and air movement to physiological experience. For example, air at 80F DB, 70F WB, moving at 20 feet per minute produces the same sensation of warmth as air at 90F DB, 60F WB, moving at 100 feet per minute. Test data (21) indicates the range of comfort between 64 E.T. and 79 E.T. with an optimum of about 71 E.T. Body heat balance calculations give a desirable upper limit of about 85E.T. Above this, deep body temperature would be

expected to rise. The Navy (22) considers 85 E.T. as the limit for moderately hard work. In hot spaces of ships underway, an E.T. of 91F is considered tolerable during usual 4-hour watches.

The main cause of increased psychrometric conditions within a shelter is body heat output. For persons tested in shelter confinement this varied from 480 BTU/HR to 520 BTU/HR. (9) According to ASHRAE (21) this could be as low as 400 BTU/HR for persons seated at rest and as high as 1500 BTU/HR for persons doing heavy work. For this study we will use a conservative value of 500 BTU/HR with side investigations of the effects of higher and lower values.

Body heat output is the sum of losses by radiation, convection and evaporation. These vary with mean radiating temperature, air movement and temperature, the partial pressure of water vapor in the air and other factors. Taking all of these into account, it is possible with rather extensive calculations to come up with precise estimates as to the amount of sensible (radiative and convective) and latent (evaporative) heat given off by a person in a specified environment. A highly simplified procedure for apportioning the amounts of sensible and latent heat (less accurate but adequate for our purposes) for a person producing 500 BTU/HR is this:

> From the ASHRAE Guide, assume linear relationships for latent heat and sensible heat as a function of dry-bulb temperature. Assume further that the boundary conditions are $Q_L = 0$ when $t_{db} = 63.5$ and $Q_S = 0$ when $t_{db} = 100$ then -

$$Q_S = 13.7\ (t_{db} - 63.5)\ \text{BTU/HR}$$
$$Q_L = 13.7\ (100 - t_{db})\ \text{BTU/HR}$$
and
$$Q_S + Q_L = 500\ \text{BTU/HR}$$

in which Q_S and Q_L are the rates of sensible and latent heat respectively; and t_{db} is the dry-bulb temperature.

Another set of criteria which greatly influences performance is the outside psychrometric design condition. Normal procedure for designing environmental control systems usually involves sizing equipment based upon severest* outdoor conditions to

* In this case, severest summertime conditions since we are essentially involved with a heat dissipation problem.

be expected.

Air conditioning engineers usually select design dry- and wet-bulb conditions from the ASHRAE Guide at the 1 or 2-1/2 percentile level. This means that based on past records the figures shown will not be exceeded by more than 1 or 2-1/2 percent during all the hours in the summer months of June through September. For this study we have followed present OCD and GSA* practice and selected values at the 5% level. Further, since this is a general study, we have used average temperatures of 90F DB and 75F WB at this level based on weighted values for the Continental United States. The "averaging" procedure is shown in Table 2.2. A more detailed picture of the variations in dry- and wet-bulb temperatures at the 5 per-centile level across the nation can be ascertained from the contour maps shown on Figures 2.1 and 2.2.

There are certain other conditions which we have chosen for this study. Among these are minimum and maximum ventilating rates, a minimum rate for recirculated air, a CBR filtering requirement, and ground and ground water temperatures for heat transfer calculations. These were selected because they either represent present OCD practice of they appeared likely to have an effect on shelter configuration. Other criteria will be established, as required, in the individual sections of this report. A summary of criteria is given in Table 2.3.

2.2.4 ACCESS, LOADING AND EGRESS

Among the primary factors used in determining overall shelter performance is entry capability. Generally, planners measure this in terms of the time required to load the shelter to rated capacity after a warning signal is given. Performance calculations will vary from shelter to shelter according to local conditions such as transportation, population distribution, time of day, travel rates, warning effectiveness and the like. For the purposes of this study, it seemed desirable to select a reasonable entry criterion and hold it constant for the various configurations. As such, we have taken the entry time at 5 minutes which translated into loading rates is 20 persons/minute for the

(text continued on page 17)

* General Services Administration

TABLE 2.2

Summer Design Conditions - 5% Level*

	Design DB	Design WB	Pop.+	Weighted DB	Weighted WB
	°F		%	°F	
Chicago	90	75	20.2	18.2	15.3
New York	88	75	19.1	16.8	14.4
Boston	84	73	5.9	5.0	4.4
Atlanta	91	76	14.5	13.2	11.1
Birmingham	91	77	6.7	6.1	5.2
Austin	95	77	9.7	9.2	7.6
Omaha	94	76	8.6	8.1	6.5
Denver	91	63	3.8	3.5	2.4
Los Angeles	86	70	11.5	9.9	8.1
			Totals -	90.0	75.0

*ASHRAE Guide, 1961 pages 451 - 458.

+Of the surrounding area - from the World Almanac, 1961.

TABLE 2.3

Summary of Environmental Design Data

Minimum ventilating rate - 3 cfm/person

Maximum ventilating rate - 30 cfm/person

Maximum effective temperature (14 day) - 85F

Maximum effective temperature (24 hour) - 90F

Outside design conditions - 90F DB, 75F WB
(50 RH, 83F E.T.)

Lighting load - Neglected

Cooking load - None

Metabolic rate - 500 BTU/HR/person

Minimum conditioned air - 15 cfm/person of which
at least 3 cfm/person is
outside air.

Filtering - CBR (U.S. Chem. Corps data)

Water and soil temperature - 55F

Maximum CO_2 concentration - 3% by volume

Minimum O_2 concentration -17% by volume

100-man unit, 100 persons/minute for the 500-man unit and 200 persons/minute for the 1000-man unit. The required width of access-way(s) to fulfill this requirements will be determined from data found in the Building Exits Code of the National Fire Code. (23)

Since we are concerned with below-ground, high-quality shelters it is also important that entry criteria be chosen such that the existance of the entry does not result in reductions in overall protective values. Because of this and because we may want to use entries for other purposes*, only enclosed units will be considered. To counter the possibility of radiation streaming, the entry tunnel will have one 90 degree turn into the shelter with the main passageway placed at least 3 feet from the shelter wall. Doors will be placed at the passageway entrance and at the shelter entrance with the first door designed for blast attenuation if required.

The shelter egress problem is somewhat different mainly because there does not seem to be a time factor involved. The primary requisite for egress is that an exit be available. Concern for this is reflected in current designs (1,24) which provide a so-called "emergency exit" for a shelter with one entrance. The thinking here is that minimum requirements should be at least two widely separated means of egress with the entry serving as one. Although the performance differences between numbers, types and locations of exits have not been established for the various shelter sizes, this minimum requirement will be used herein. In addition, we will assume that all entrances may also serve as exits.

In summary, the access, loading and egress criteria are as follows:

1 - Total access shall be based on loading rate of 0.2 persons/minutes/person sheltered.

2 - Entry passageways shall be totally enclosed and provided with inner and outer doors.

* As air intake plenum chambers or particle settling chambers or for housing mechanical-electrical equipment.

3 - Each passageway shall be at least 3 feet from any shelter wall and shall contain one 90-degree bend before reaching the shelter entrance.

4 - Shelter units with one entrance shall be provided with a minimum exit furthest from the point of entry. In shelters having two or more entries, at least two shall be widely spaced.

5 - Entry design shall be based on current National Fire Code data. (23)

Other requirements are developed later in the section dealing specifically with entries and exits.

2.2.5 SHELTER SUPPORT ITEMS

In this study we will be concerned with facilities necessary to support the shelter population for the required period since these determine space requirements. Such facilities may include sleeping, seating and eating accommodations, food, water, medical and detection equipment, sanitation, environmental control items and administration. The extent to which these are provided depends upon human factors and largely upon the degree of austerity desired. It also depends indirectly on shelter sizing. For example, in large shelters it may be necessary to provide full-fledged medical services where as this may not be required in small units. Generally, large shelters have a more difficult management problem and this might result in additional space allowances.

For this investigation we have included space allowances for facilities based upon current civil defense planning (25) and partially upon the planning data used in previous studies (see Table 2.4). Generally these allowances are austere. Specific space criteria are as follows:

Toilets - 3 Ft. x 5 Ft. per unit and 1 unit for 20 persons. This allows sufficient space for any toilet type plus possible lavatory facilities. The rate at which these are furnished is a conservative estimate based upon reasonable use factors. (16)

Food and Medical Storage - 1 cubic foot per person. This is based

TABLE 2.4

SPACE ALLOCATIONS IN SOME PREVIOUS STUDIES
(Square Feet Per Person)

STUDY (CAPACITY)	AIR[14] (30)	BUDOCKS[29] (over 50)	DUNLAP[16] (1000)	NRDL[1] (100)
ITEM				
TOILETS	.54	.32	1.27	1.10
FOOD & MED.	.19	.34	.78	.58
ADMIN.	-	.50	.43	-
MECH.ELECT. EQUIPMENT	-	-	.57	-
BUNKS	4.00	-	2.43	3.00
AISLES	3.33	3.00	3.95	5.84
SEATING & TABLES	-	-	-	1.48
TOTALS	8.06	4.16	9.43	12.00

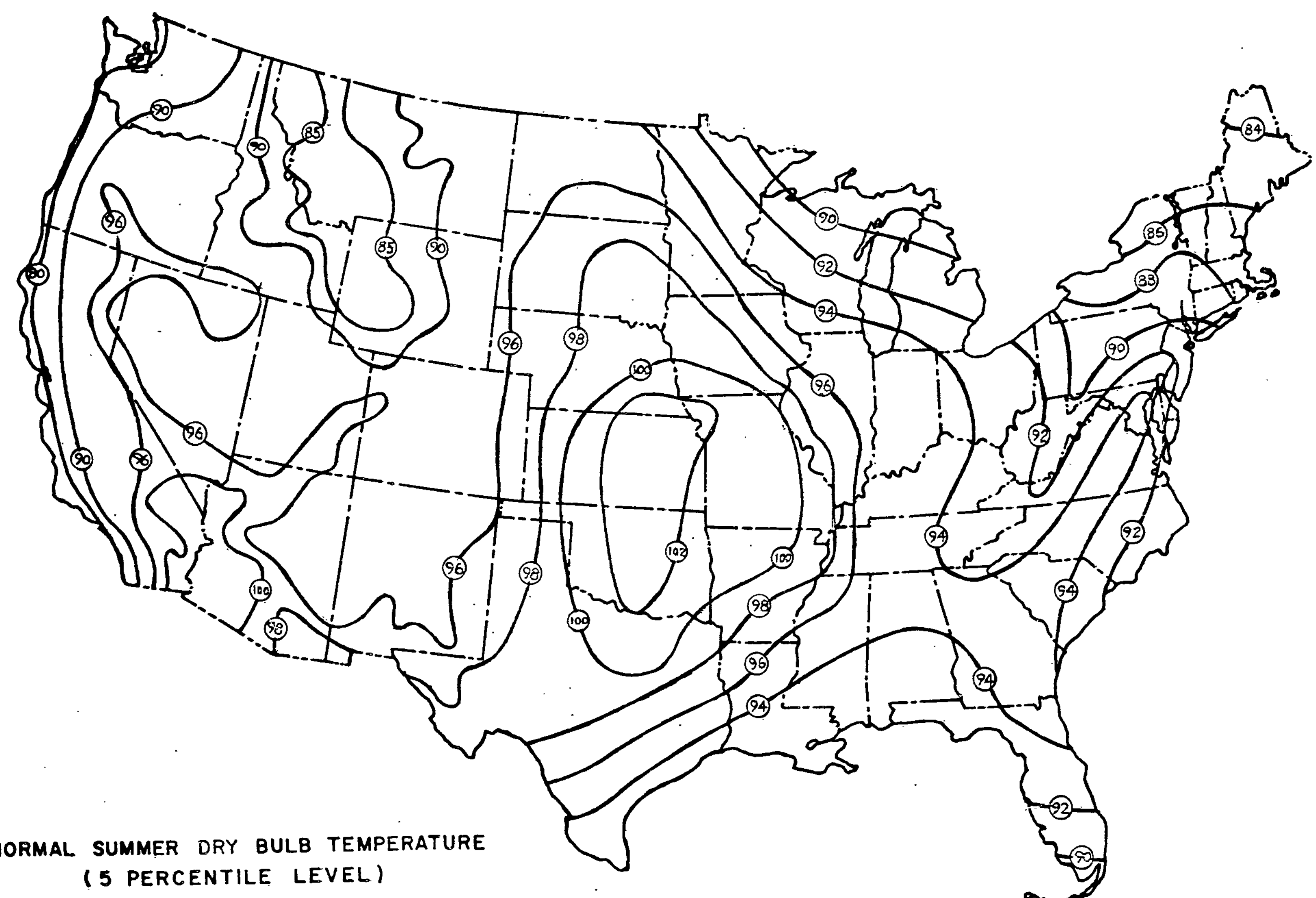
on the current stocking program food and medical package except that we have allowed food storage at the rate of 2,000 calories per person per day.

Administration - 0.5 square feet per person. This is assumed to include control space and any food preparation area needs.

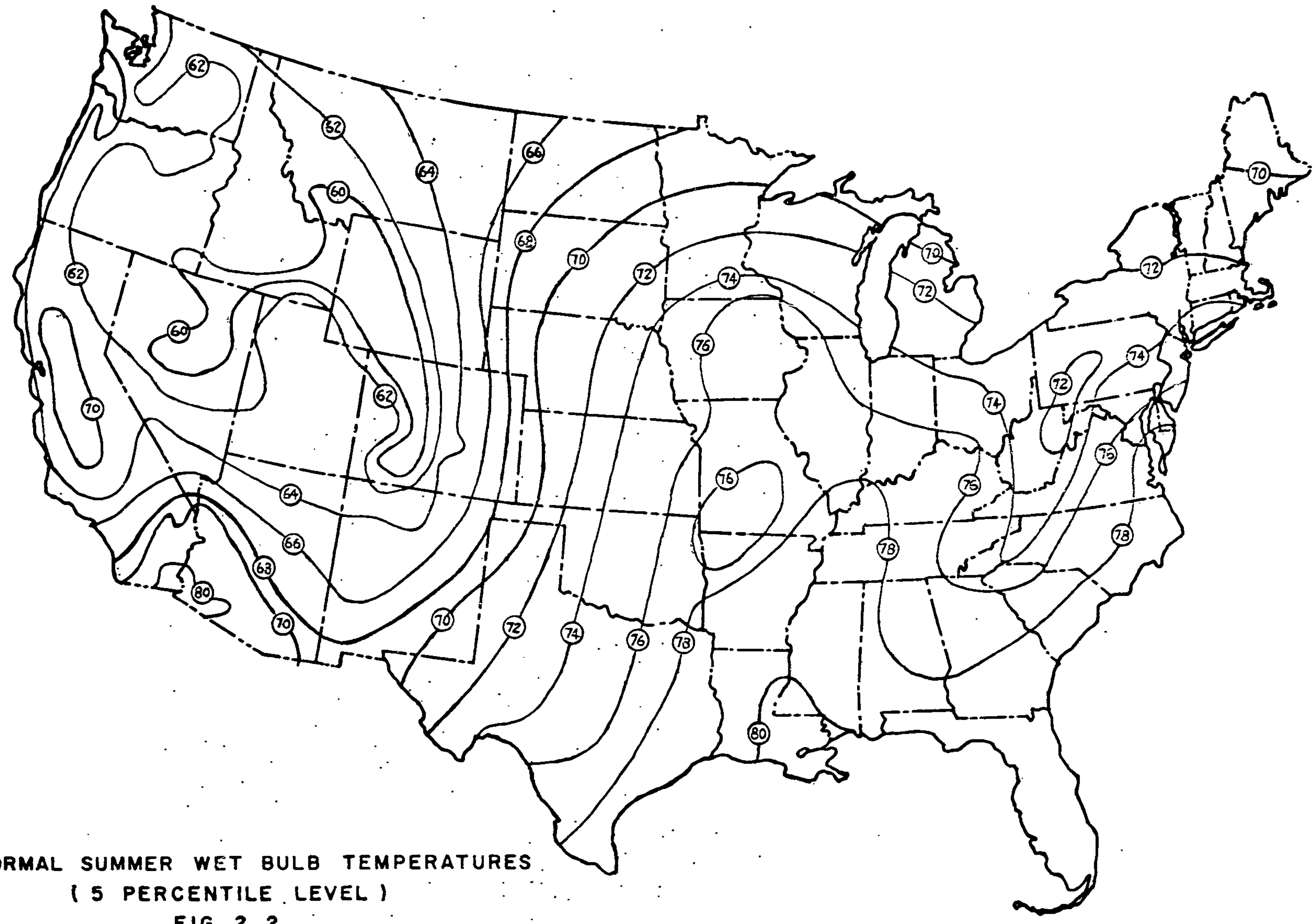
Space requirements for mechanical-electrical equipment, bunking, seating and access aisles are developed in other sections of this report. Areas for these items cannot be arbitrarily chosen since they will vary from configuration to configuration.

This study does not include space allowances for water, sanitation or fuel storage since it is not obvious that these will be required within the shelter or that their inclusion will materially affect the selection of optimum configurations.

(text continued on page 23.)



NORMAL SUMMER DRY BULB TEMPERATURE
(5 PERCENTILE LEVEL)
FIG. 2.1



NORMAL SUMMER WET BULB TEMPERATURES
(5 PERCENTILE LEVEL)
FIG. 2.2

SECTION 3

STRUCTURAL ANALYSIS

3.1 SCOPE

This section is a summary review of the structural procedures and techniques used in this study and the results derived therefrom.

3.2 SELECTION OF PARAMETERS

There are many structural factors which affect shelter configuration and cost. Such factors include design over-pressure, location with respect to ground elevation, soil conditions, structural system, construction materials and size. These are really variables whose interaction complicates the overall problem.

In this study, we have attempted to avoid overly complicating the structural analysis by placing limitations on the range and number of parameters. With some recapitulation of performance criteria (Section 2), structural design data is as follows:

1 - Overpressure - For this study, we have selected the minimum resistance level for a blast shelter at 35 psi. Two other pressure levels are also studied for their cost influence. These are 60 psi and "nominal live-load". The latter is associated with structures designed for fallout only with a nominal live-load surcharge of 300 pounds per square foot such as might be delivered to a structure under a playground or park.

2 - Capacity - Three sizes are considered - 100, 500 and 1000 - person units.

3 - Structural Types - Three basic shapes are considered - semi-circular arches, hemispheres (domes) and rectangular "boxes".

4 - Soil Conditions - We have assumed a medium compact

soil free from rocks. Complications due to ground water are not included. Ground surface is assumed level before and after installation. Minimum cover is 3 feet.

3.3 DESIGN METHOD

Generally, the structural analyses are based on procedures given in the unclassified portions of Reference 26 and Reference 27. These are simplified procedures intended for preliminary design of structures and structural elements subject to dynamic loading. The accuracy of results is estimated by the authors to be within 20 to 25%; a justifiable range since some of the basic loading criteria cannot be more accurately defined.

These design methods establish relationships between the peak dynamic force applied to a structure or structural elements, the static resistance of the element, the effective duration of the force, the period of vibration of the element and the ratio of total element deflection to its deflection in the elastic range. These parameters have been reduced to chart form for various shapes with the ductility factor (μ) as the degree of freedom. This parameter, defined as the ratio of the permissible maximum deflection to the "effective yield point" deflection, was taken from the above references at 1.3 for the design of concrete elements in pure shear and cracking, and 3.0 for flexure and diagonal tension. Structural steel members were designed for $\mu = 3.0$.

Material stresses used herein are as follows:

Structural Carbon Steel (ASTM A7)

f_{dy} = dynamic yield point in tension or compression = 42,000 psi

V_{dy} = dynamic yield point in shear = 25,000 psi

Reinforcing Steel (Intermediate Grade)

f_{dy} = 52,000 psi

Concrete

f'_{dc} = dynamic compressive strength = $1.25\ f'_c$; where f'_c

= standard 28-day compressive strength. (3000 psi)

V_{dy} (pure shear) = 0.15 f'_c

μ_d = 0.15 f'_c = Allowable dynamic bond stress on deformed bars (A 305)

ϕ = Percentage of reinforcing steel to concrete = 1.5%.

Soil Bearing Capacity

Sp = Allowable soil-bearing pressure = 2 (8000 + 200h) psf; where h = depth, finished grade to bottom of footing, less 3 feet.

3.4 PROCEDURE

This part of the report discusses the various structural analyses.

3.4.1 RECTANGULAR BOX STRUCTURE

The investigation of rectangular configurations was conducted in 5 separate parts:

1 - A study of column bay spacing versus roof cost.

2 - A study of the effect of varying aspect ratio.

3 - A cost comparison between one and two-level structures.

4 - A comparison of structures accommodating 4 and 5 high bunking (7'-4" headroom and 9'-0" headroom).

5 - The determination of optimum cross-section.

3.4.1.1. Column Bay Spacing versus Roof Cost

Several types of roof systems are available for consideration. Among these are the concrete, or concrete and steel, beam and girder system; and flat slab; and waffle-pan construction. A beam and girder system consisting of a reinforced concrete roof slab, rolled steel beams and girders and steel columns with concrete

footings was used for this investigation. We selected this system as representative of cost-competitive blast resistant roof construction for reasons of relative simplicity and adaptability to rapid calculation.

An evaluation was made by costing ranges of typical interior bay sizes with varying framing schemes. Beams spans were considered from 8' to 28' in 4-foot increments; beam spacing from 4' to 16' to 2-foot increments and girder spans from 8' to 28' in 2-foot increments. In all cases the limiting spans were determined by the maximum dynamic capacity of the largest available rolled steel section, 36WF300. Slabs were considered to be one-way or two-way depending on the framing arrangement.

The resulting costs including column and column foundation costs are shown on Figures 3.1, 3.2 and 3.3. Figure 3.1 has the space between beams equivalent to the girder length. Figure 3.2 has a beam spacing of one-half the girder length. Figure 3.3 has a beam spacing of one-third the girder length. Each figure shows a family of curves, one for each given girder length, with beam span as the abscissa and cost in dollars per square foot as the ordinate.

This data shows that the cost per square foot of roof system:

decreases for any given girder length as the beam span is reduced;

decreases for any given beam span as the girder length is reduced;

decreases slightly for a given column bay size as the beam spacing approaches the girder length(square framing).

For example an 8' by 8' roof system would be expected to cost $4.25 per square foot in comparison to a $6.50 per square foot cost for a 16' by 16' system.

These curves were extrapolated to determine the roof cost for a bay size of 6'-4" x 6'-4" (dimensions later ascertained, to be modular for bunk spacing). This roof, costing $3.60 per square foot, was used in subsequent determinations of rectangular cross-section shelter costs.

3.4.1.2 Aspect Ratio

On a tentatively assumed area basis of 12 square feet per person, a study was made to determine the cost influence of aspect ratio (ratio of length to width) for shelters of 100-, 500- and 1,000-person capacity. Relative costs of shelters were computed using varying aspect ratios with outside wall heights of 10'-6" and 13'-0". The results, shown on Figure 3.4, indicate that cost varies directly with aspect ratio and is lowest for a square configuration. The cost variation is less marked for the larger capacity shelters than the smaller ones.

3.4.1.3 One-Level vs. Two-Level

Again on a preliminarily assumed area basis of 12 square feet per person, a 9'-0" clear inside height (5 bunks high) and a nearly square configuration, a study was made to compare costs of 100-, 500- and 1,000-person capacity shelters between one-level and two-level structures.

The results, shown in Figure 3.5 (which is a plot of shelter structure cost in dollars per square foot of floor area vs. shelter capacity), show that in each case a one-level structure is more economical than a two-level structure.

A two-level shelter structure is estimated to cost from 9-13 per cent more than a single-level structure; the cost differential is higher for the large shelter than for the small one. The reason for this is that the cost of burying the structure an additional level is greater than the cost of spreading it out over a larger area. If construction conditions change or if real estate costs are considered, two- (or more) level structures may prove optimum.

3.4.1.4 Story Heights

This part, because of its direct relationship to the bunking schemes, is described in detail in Section 4. It can be noted here, however, that it was concluded that a story height of 7'-4" (corresponding to 4-high bunking) is more economical than 9'-0" (5-high bunking).

3.4.1.5 Optimum Cross-Section

As a result of the foregoing preliminary investigations

and concurrent area utilization studies, the optimum cross-section dimensions of the rectangular shelters for 100, 500 and 1,000 persons, respectively, were determined to be as shown on Figure 3.6.

A tabulation of estimated costs for these structures is given in Table 3.1 for 35 psi. The same three shelters were studied to determine the effect on cost of providing a 60 psi blast resistance capability and a nominal live-load capability. The 60 psi structure was designed by the same methods as the 35 psi structure and the nominal live-load condition by conventional design methods. The nominal live-load design results in inherent blast protection of about 5 psi. Final rectangular unit designs are shown and discussed in Section 7.

3.4.2 CORRUGATED STEEL ARCHES

These structures were analyzed as thin compression rings utilizing the empirically derived ultimate static seam loads shown below:

Steel gage	Ultimate Static Seam Load --(Lbs.)
1	144,000
3	131,000
5	113,000
7	93,000
8	80,000
10	62,000
12	42,000

Blast pressures and soil overburden dead load were considered to be statically applied. Depth below ground was established so that the average earth cover was at least one quarter of the diameter. However, buckling was not considered since this would have resulted in heavier gage steel than was proved necessary in actual tests performed on similar buried structures. Test data (28) compare favorably with the results obtained from the above-described method. While the procedure is deemed adequate for cost comparison purposes desired in this study, it should be noted here that a more rigorous analysis must be applied in the design stage. Such methods were not warranted here because of the uncertainty of such basic design criteria as backfill characteristics and

TABLE 3.1

UNIT COSTS FOR A 35psi

RECTANGULAR STRUCTURE

ITEM	UNIT	COST
Roof System	Square Foot	$ 3.60
Walls	"	1.70
Floor Slab	"	0.40
Expansion Material	"	0.30
Waterproofing	"	3.20
Foundation Concrete	Cubic Yard	38.00
Excavation	"	0.97
Backfill	"	0.80

permissible plastic deformations. The maximum diameters determined for each standard gage are shown on Figure 3.7.

In order to utilize the headroom created by the larger arches (30'-0" and over), it was decided on the basis of economics to add interior levels. These floors were designed for 100 PSF* live-load by conventional analysis, and are considered independent of and not connected to the arch sidewalls. For cost comparison purposes a steel frame with poured concrete deck was assumed. The average cost of such a system was estimated at $1.88 per sq. ft., and was used in all subsequent costing of multi-level structures.

Cellular steel panels were used as endwalls and these were designed in accordance with Reference (26) for a third of the side-on blast overpressure plus dead load. Steel wales braced by dead men are used as intermediate horizontal supports for the 16'-0" and 23'-0" diameters, while the interior floor slabs are used as supports for the larger spans. In all cases an 18" channel section is used as a peripheral support to distribute the endwall compressive load to the arch.

Foundations were designed in accordance with the soil-bearing capacities given in Paragraph 3.3. The floor slab is designed independent of the foundations or "floating" so as to avoid stress in case of settlement under load.

Cost estimates of the components of the 35 psi version of these shelters are given in Table 3.2.

For the 60 psi arch, gages were increased for all sizes and stiffening ribs added for the 44'-0", 49'-0" and 57'-0" diameter arches.

Except for a reduced steel gage in the endwalls, no change was made on the 35 psi arch for the nominal live-load condition. The effect is a structure which will withstand the design loading but with more deflection or deformation than would probably be accepted by local building authorities. However, since conformity with building code requirements for this loading condition would

* American Institute of Steel Construction's Standard for public areas.

TABLE 3.2

UNIT COSTS FOR 35 psi CORRUGATED

STEEL ARCH STRUCTURES

ITEM	16'	23'	30'	35'	44'	49'	57'
Excavation	14.85	26.70	42.60	56.60	89.00	110.30	145.30
Backfill	8.81	14.40	23.20	30.80	48.40	59.60	78.00
Arch Steel	42.84	66.54	94.01	115.41	161.5	193.81	237.46
Concrete(Fdn)	9.65	13.75	11.90	14.10	17.70	20.40	24.80
Concrete(Slab)	4.22	6.15	8.15	9.20	10.20	13.40	15.70
Waterproofing & Protection	8.93	12.85	16.79	19.55	24.60	27.40	31.80
Floor Hardener	0.96	1.39	1.84	2.15	2.71	3.04	3.56
Expansion Mat'l	0.68	0.72	0.76	0.79	0.84	0.86	0.91
TOTAL COST/L.F.	90.94	142.50	199.25	248.60	355.02	429.81	537.53
END WALL COSTS	16'	23'	30'	35'	44'	49'	57'
Fdn & Ftg Concrete	51.30	134.00	208.00	246.00	389.00	498.00	658.00
Excavation	135.80	375.00	585.00	857.00	1710.00	2320.00	3395.00
Backfill	112.00	253.50	483.00	717.00	1408.00	1914.00	2800.00
End Wall	599.00	987.00	1500.00	1965.00	2950.00	3570.00	4714.00
Waterproof & Protection	38.40	79.50	135.20	184.00	292.00	361.00	493.00
TOTAL COST-1 Wall	936.50	1829.00	2911.20	3969.00	6749.00	8663.00	12060.00
TOTAL COST-2 Walls	1873.00	3658.00	5822.40	7938.00	13498.00	17326.00	24120.00

result in a more costly structure than is required for 35 psi, the problem is not considered here.

The cost comparisons for the three blast capabilities are discussed in Section 7.

A precaution to be observed in the construction of large steel arches, and a possible disadvantage, is the problem of backfilling. Since the arch itself is flexible and derives its strength considerably from the surrounding soil, special attention must be given to this phase of construction. Only select materials, properly placed and tamped and especially well specified and supervised, should be used if the arches are to develop the necessary side support. It may be that in certain areas because of soil conditions, lack of qualified contractors, etc., these requirements may be difficult to fulfill. In such cases consideration should be given to other shelter structures.

3.4.3 CONCRETE ARCHES

Concrete arches were analyzed in accordance with Reference (26). Seven diameters, corresponding to those determined for corrugated steel arches, were studied so as to form a basis for comparison. Slabs were designed to be "floating" and the foundations designed for the soil-bearing capacity given in paragraph 3.3. The average depth below ground was maintained so that minimum cover at the crown is 3'-0".

The selected reinforced concrete arch cross-sections with wall and main floor slab thickness for the range of sizes investigated are shown on Figure 3.8.

Interior floors were utilized for arches of 30'-0" diameter and over, and were costed at $1.88 a square foot. These floors also serve as intermediate supports for the end walls.

End walls were considered to be poured, reinforced concrete, designed for one third of the side-on blast over-pressure plus dead load. No dead men were used. The entire compressive load is transferred to the arch itself; or, to the intermediate floor slabs.

Cost estimates of the components of the 35 psi version of these shelters are given in Table 3.3.

TABLE 3.3

UNIT COSTS FOR 35 psi REINFORCED

CONCRETE ARCH STRUCTURES

ITEM	16'	23'	30'	35'	44'	49'	57'
Excavation	16.70	28.70	40.03	52.40	77.10	98.50	128.50
Concrete (Arch)	37.90	78.50	138.50	189.00	304.00	374.00	548.00
Concrete (Fdn.)	9.65	13.75	11.90	14.10	17.70	20.40	24.80
Concrete (Slab)	4.22	6.15	8.15	9.20	10.20	13.40	15.70
Backfill	9.52	15.75	20.90	26.30	36.90	48.10	61.00
Floor Hardener	0.96	1.39	1.84	2.15	2.71	3.04	3.56
Expansion Material	0.68	0.72	0.76	0.79	0.84	0.86	0.91
Waterproofing & Protection	9.22	13.30	17.45	20.30	25.60	28.40	33.30
TOTAL COST PER L. F.	88.85	158.26	239.53	314.24	475.05	586.70	815.77
END WALL COSTS	16'	23'	30'	35'	44'	49'	57'
Foundation & Ftg Concr.	51.30	134.00	208.00	246.00	389.00	498.00	658.00
Excavation	155.00	341.00	547.00	773.00	1,320.00	1,900.00	2,810.00
Backfill	128.00	282.00	451.00	637.00	1,090.00	1,570.00	2,320.00
Wall Concrete	128.00	341.00	547.00	748.00	1,177.00	1,463.00	2,000.00
Waterproofing & Protection	38.40	79.50	135.20	184.00	292.00	361.00	493.00
TOTAL COST - 1 WALL	500.70	1,177.50	1,888.20	2,588.00	4,268.00	5,792.00	8,281.00
TOTAL COST - 2 WALLS	1,001.40	2,355.00	3,776.40	5,176.00	8,536.00	11,584.00	16,562.00

If these structures were designed by using conventional methods and building code requirements, the cost would be larger than was necessary for 35 psi. No consideration was given to this discrepency. Results of the 35 psi and 60 psi structures are presented in section 7.

3.4.4 CONCRETE DOMES

Concrete domes were analyzed by the methods indicated in Reference (26). As a preliminary indication of capacity, 7 hemispherical domes of 16', 23', 30', 35', 44', 49', and 57' diameter were analyzed and costed.

Slabs were designed to be "floating" and foundations designed in accordance with soil-bearing capacities given in Section 3.3. The average depth below grade was maintained at one-eighth of the diameter with 3'-0" minimum cover at the crown.

Interior floors were utilized in the larger domes and were designed as previously stated. The cost estimate used for these floors was $1.88 per sq. ft.

Figure 3.9 illustrates the seven domes that were analyzed. Two shell thicknesses are shown, the theoretical or calculated thickness and the actual which is the minimum thickness dictated by construction practice for concrete placement and coverage of reinforcement. The theoretical thickness varies from 0.8 inches to 3.0 inches whereas the actual is 3 inches for all sizes analyzed.

Table 3.4 is a tabulation of the estimated costs for the 35 psi version of the domes studied.

The same criteria regarding shell thickness was applied to domes for the nominal live-load condition resulting in no significant change in cost between the nominal live-load type and the 35 psi type. 60 psi domes were also investigated and costed and a comparison of the costs of these three series of domes is given in section 7.

3.5 COSTS

The estimated cost of the structures studied herein are

TABLE 3.4

UNIT COSTS FOR 35 psi REINFORCED

CONCRETE DOME STRUCTURES

ITEM	16	23	30	35	44	49	57
Excavation	407.00	925.00	1770.00	2600.00	4650.00	6130.00	9110.00
Backfill	297.00	655.00	1210.00	1750.00	3100.00	4050.00	5950.00
Concr.(Dome)	743.00	1540.00	2620.00	3560.00	4630.00	5730.00	9500.00
Concr.(Fdn.)	76.00	152.00	399.00	513.00	722.00	836.00	1010.00
Concr.(Slab)	50.00	112.50	188.00	263.00	413.00	512.00	714.00
Waterproof & Protection	143.00	297.00	502.00	685.00	1085.00	1340.00	1820.00
Hardener	12.40	25.40	43.00	58.50	94.10	116.00	160.00
Expans. Mat'l.	14.10	20.80	26.40	30.90	51.30	57.30	67.20
Total Cost	1742.50	3727.70	6758.40	9460.40	14745.40	18771.30	28331.20

based generally upon Building Construction Cost Data 1962 by R. S. Means. These costs represent national averages for U.S. metropolitan area construction.

It should be recognized that differences in locale with consequent changes of material and labor costs will affect the cost estimates given here.

All structures costed have been assumed to be in medium compact soil without large quantities of rock, and with ground water below foundation level. Sites with unusual or difficult foundation conditions, or those requiring other than spread footings of the sizes estimated, will increase the construction cost.

Table 3.5 is a summary of unit costs used in this study. These costs reflect labor and material for construction installed complete and in place. They do not include contractor profit and overhead, contingency allowance, or engineering fees. These items, which do not affect the comparisons drawn in this report, will increase the indicated shelter costs by about 50 to 75%.

No attempt was made to estimate the cost of utility connections, clearing grading and drainage, or architectural treatments such as landscaping or painting. These items can vary widely from site to site and will not influence the cost comparisons made here.

(text continued on page 48.)

TABLE 3.5

Summary of Unit Costs

Item	Unit	Unit Cost - $
Concrete in place incl. forms and reinforcing:		
Walls	C. Y.	55.00
Foundations	C. Y.	38.00
Floor slab	C. Y.	27.00
Roof deck	C. Y.	85.00
Arches*	C. Y.	140.00
Domes*	C. Y.	200.00
Structural Steel	TON	258.00
Excavation	C. Y.	0.97
Backfill	C. Y.	0.80
Damp roofing and protection	S. Y.	3.20
Expansion joint filler	L. F.	0.30
Floor Hardener	S. F.	0.07
Galvanized Steel Crating	S. F.	4.20
Dead man - Screw type	ea.	50.00
Corrugated Steel Arches**		
Span x rise - Gage	Lin. Ft. of arch	
16' x 8' 12	" " " "	42.84

TABLE 3.5 (cont'd.)

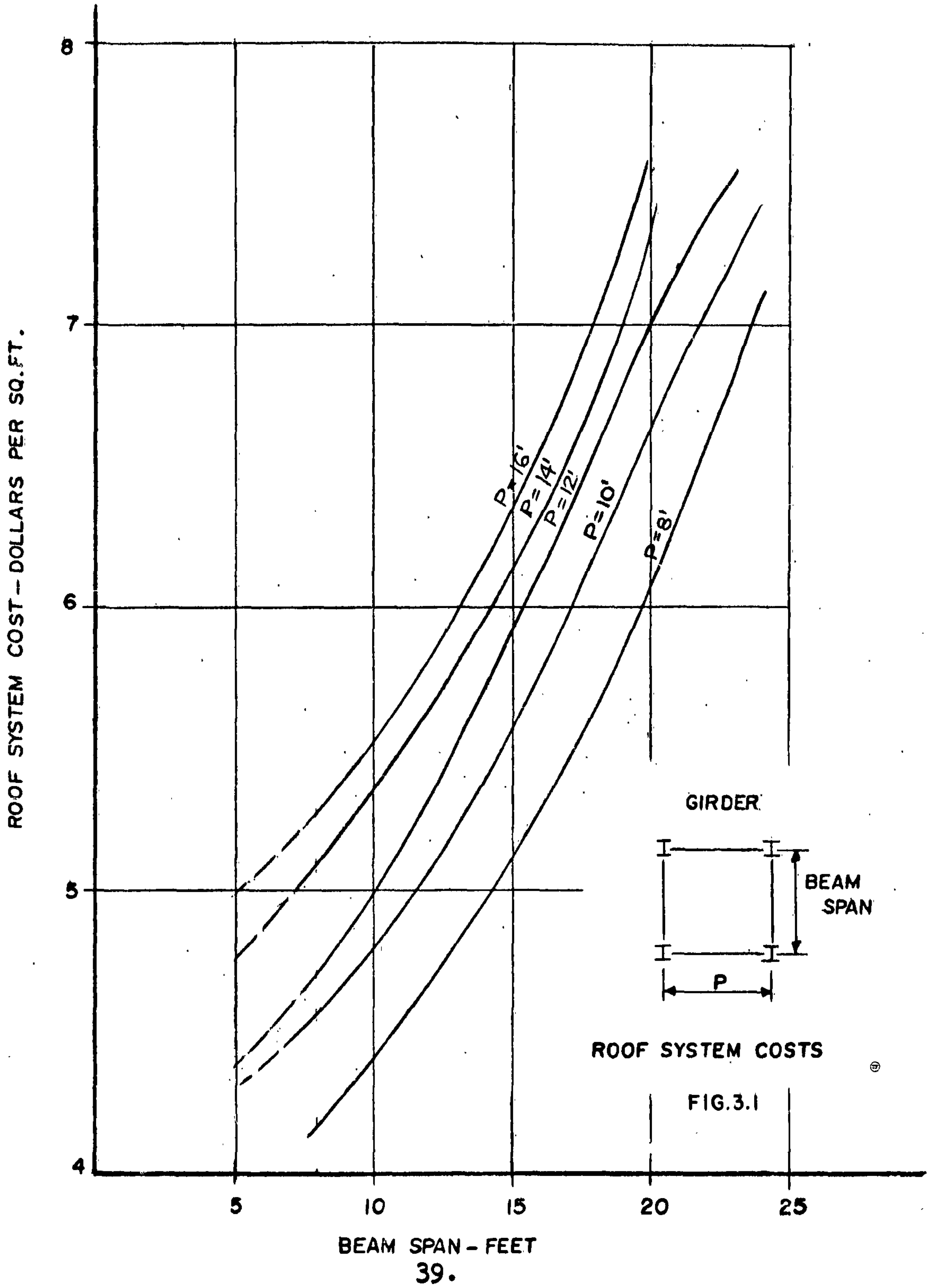
Summary of Unit Costs

Item		Unit	Unit Cost - $
Span x rise	Gage		
23' x 11.5'	10	Lin. Ft. of Arch	66.54
30' x 15'	8	" " " "	94.01
35' x 17.5'	7	" " " "	115.41
44' x 22'	5	" " " "	161.57
49' x 24.5'	3	" " " "	193.81
57' x 28.5'	1	" " " "	237.46
Entrance Package			
Hand-rail		L.F.	2.50
7'-0" Steel chain link fence		L.F.	4.90
Gate			
Single		each	65.00
Double		each	90.00
35 psi Blast Door***			
Single		each	450.00
Double		each	575.00

* see appendix A-1

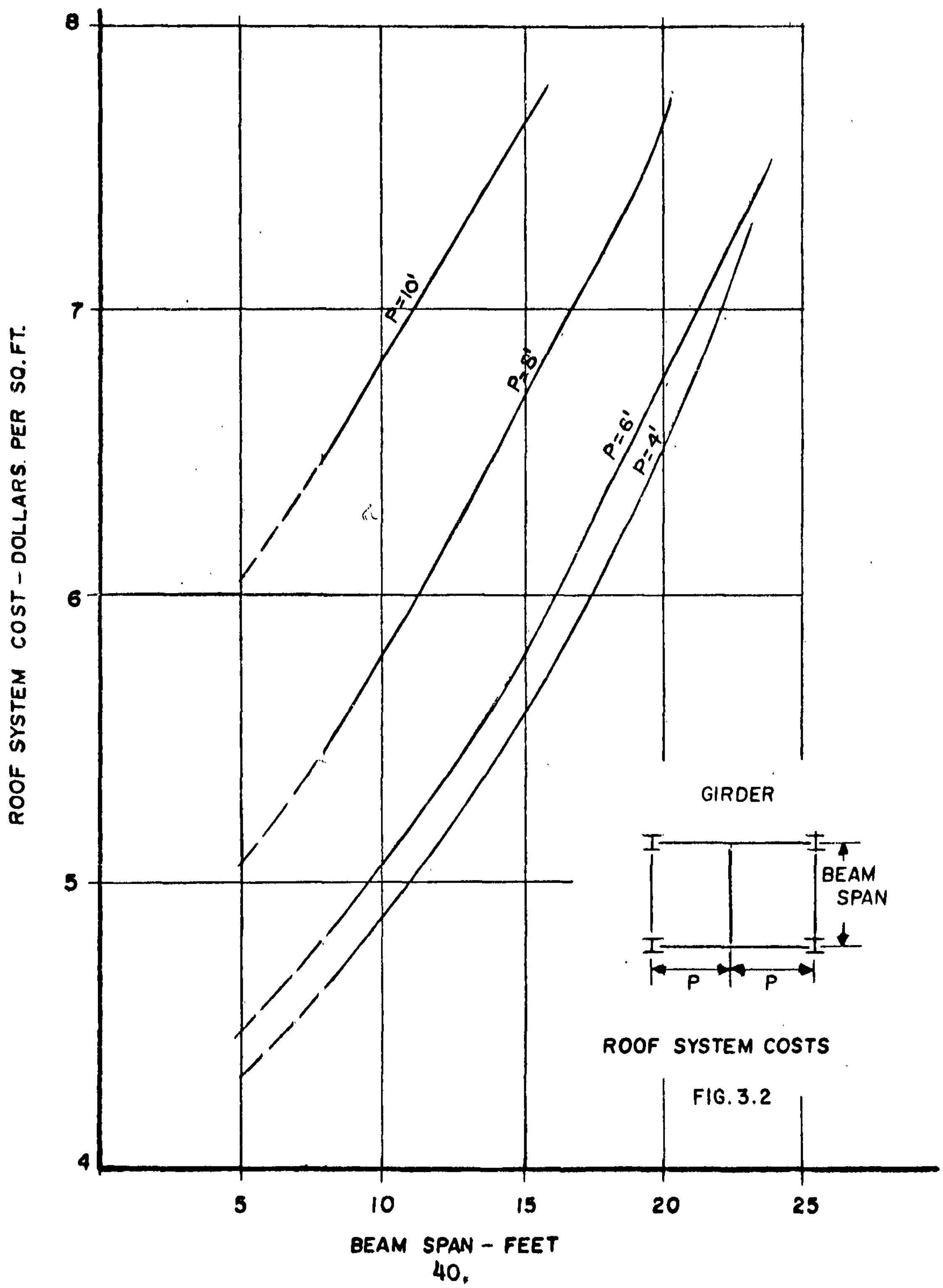
** Price information: Metal Products Division, Armco Steel Corporation

*** Lump sum Estimated Cost



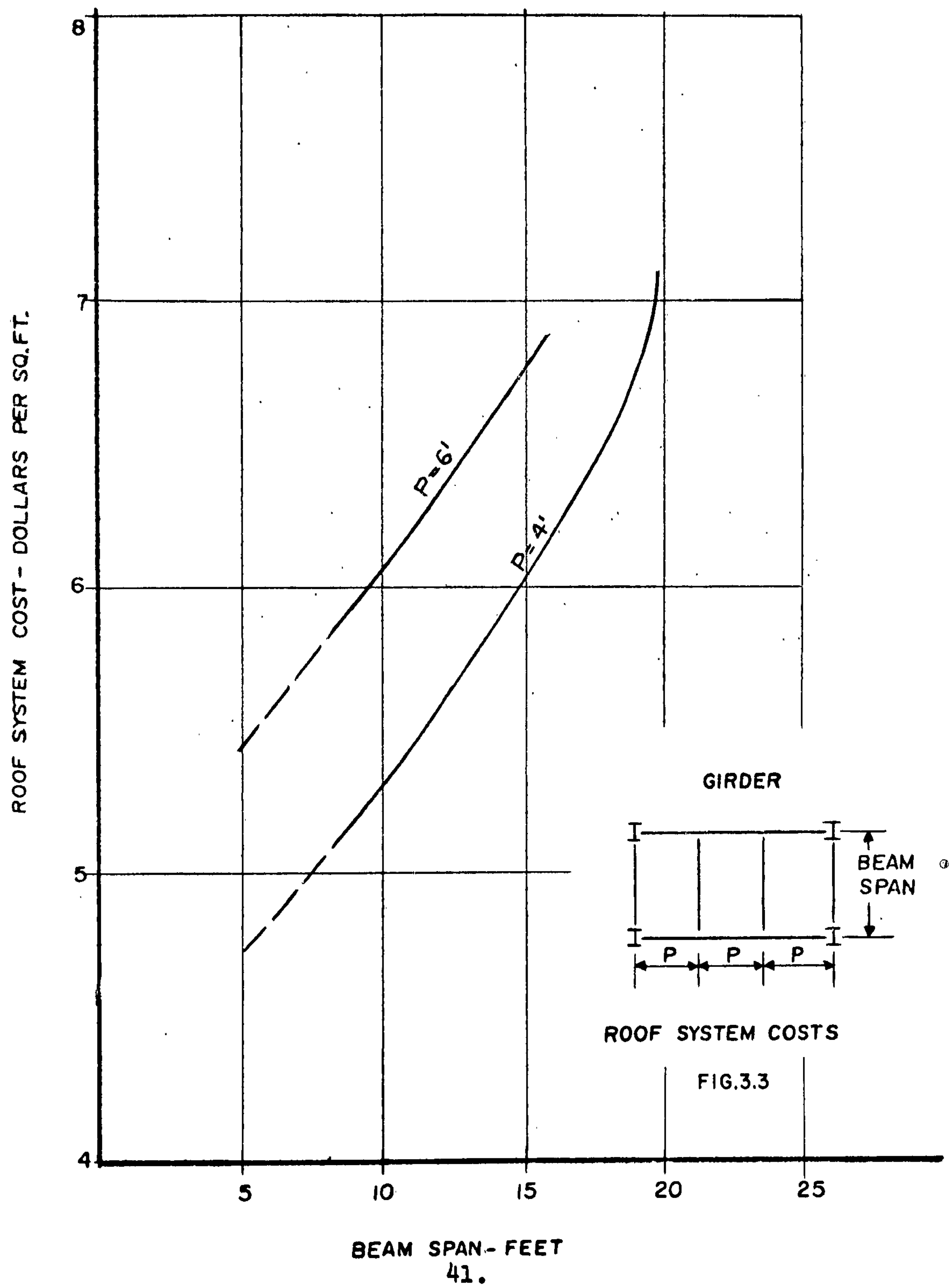
ROOF SYSTEM COSTS

FIG.3.1



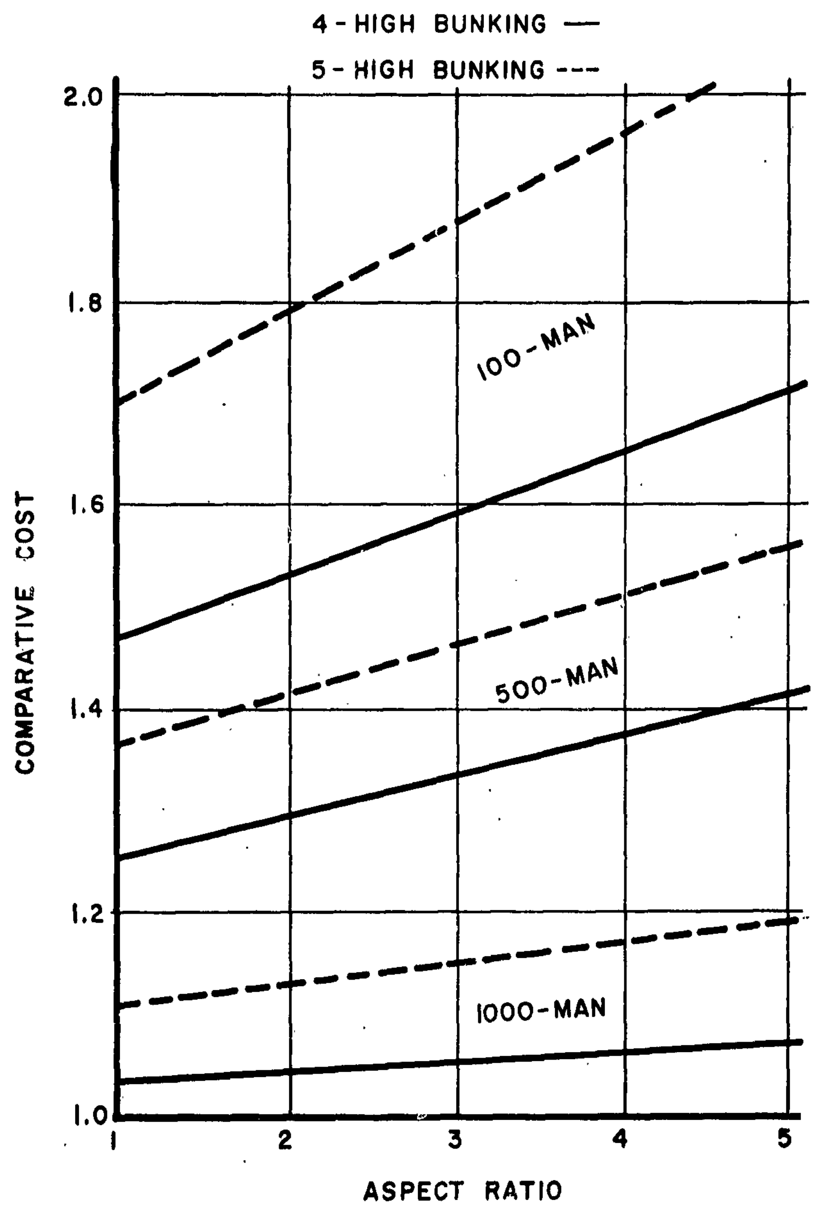
ROOF SYSTEM COSTS

FIG. 3.2



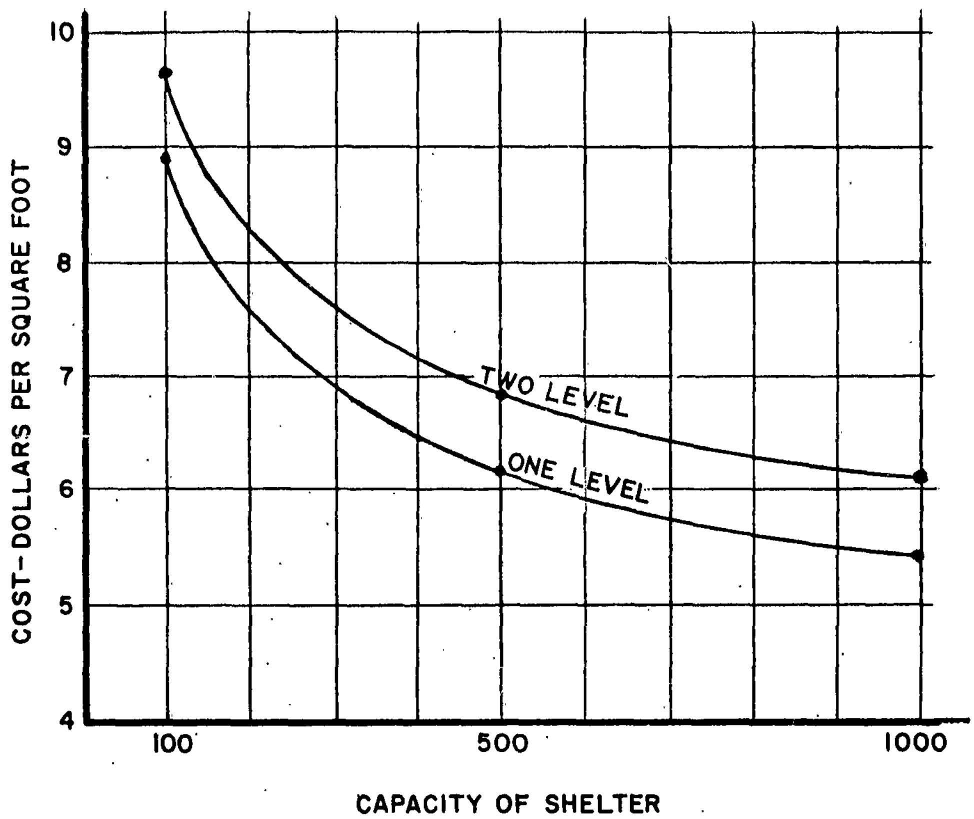
ROOF SYSTEM COSTS

FIG.3.3



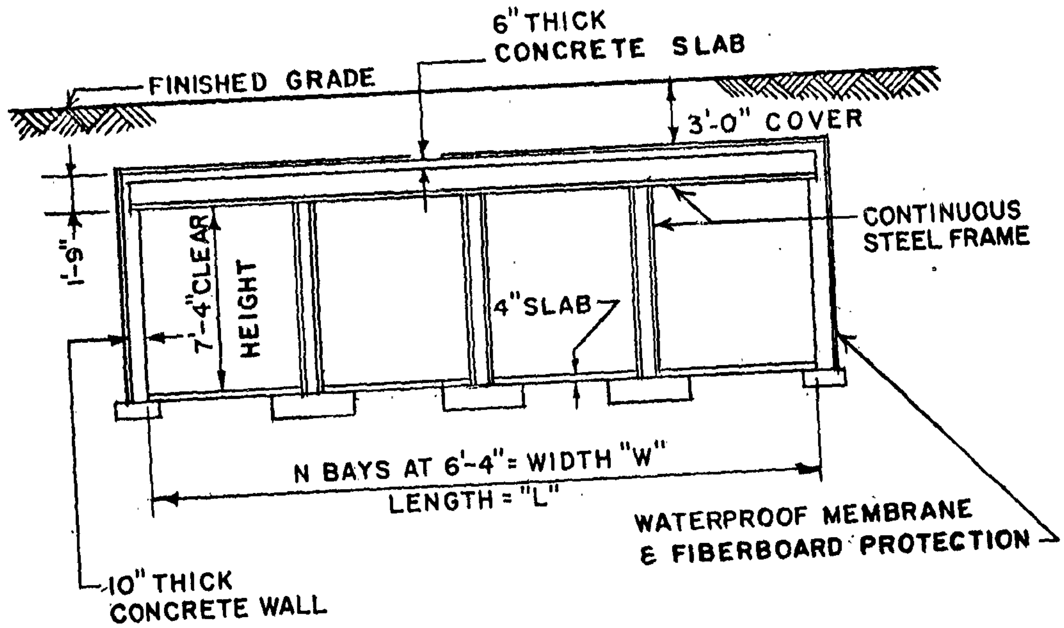
ASPECT RATIO vs. COST - RECTANGULAR STRUCTURES
(35 psi)

FIG. 3.4



COST COMPARISON-TWO LEVEL RECTANGULAR SHELTER AND ONE LEVEL RECTANGULAR SHELTER

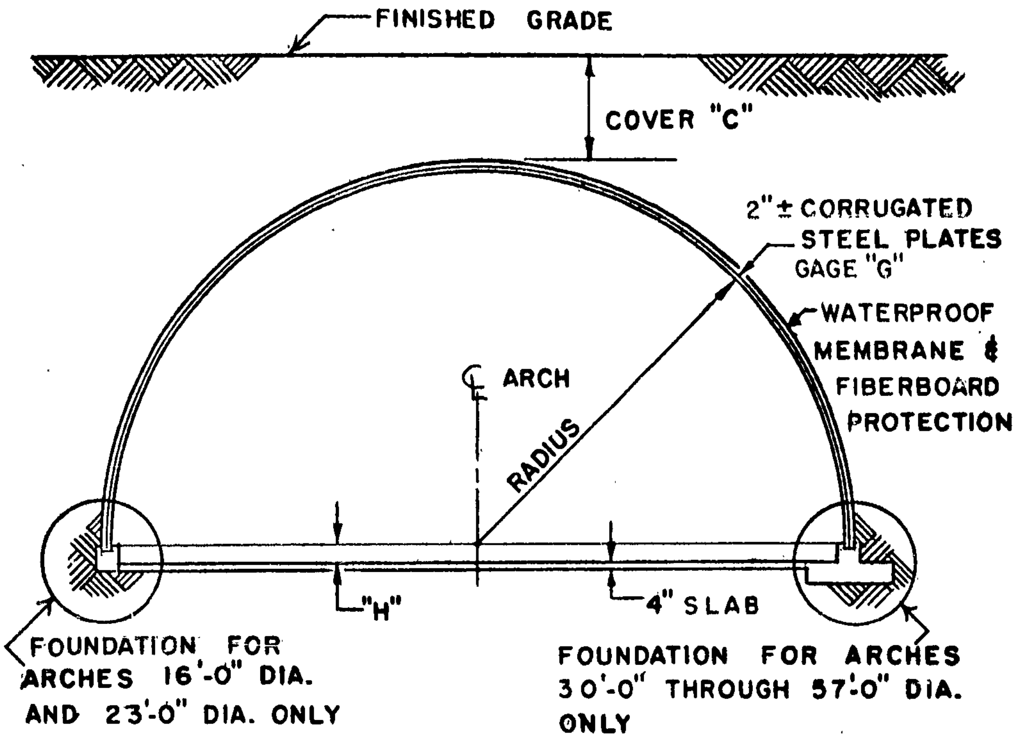
FIG. 3.5



WIDTH "W"	"N"	LENGTH "L"
25'-4"	4	32'-0"
63'-4"	10	62'-0"
88'-8"	14	84'-0"

35 PSI BURIED RECTANGULAR "BOX"-CROSS-SECTION

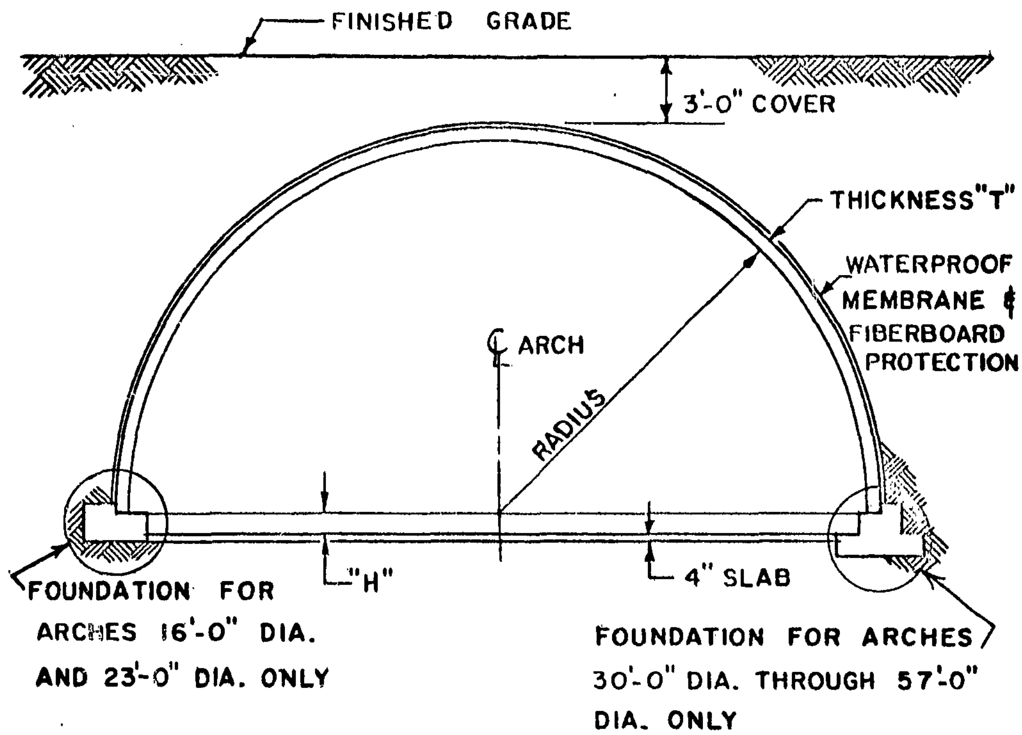
FIG.3.6



DIAMETER	GAGE "G"	COVER "C"	"H"
16'–0"	12	3.0'	8"
23'–0"	10	3.3'	1'–0"
30'–0"	8	4.3'	8"
35'–0"	7	5.0'	10"
44'–0'	5	6.3'	1'-2"
49'–0"	3	7.0'	1'-6"
57'–0"	1	8.2'	1'-8"

35 PSI BURIED CORRUGATED STEEL ARCH–
CROSS-SECTION

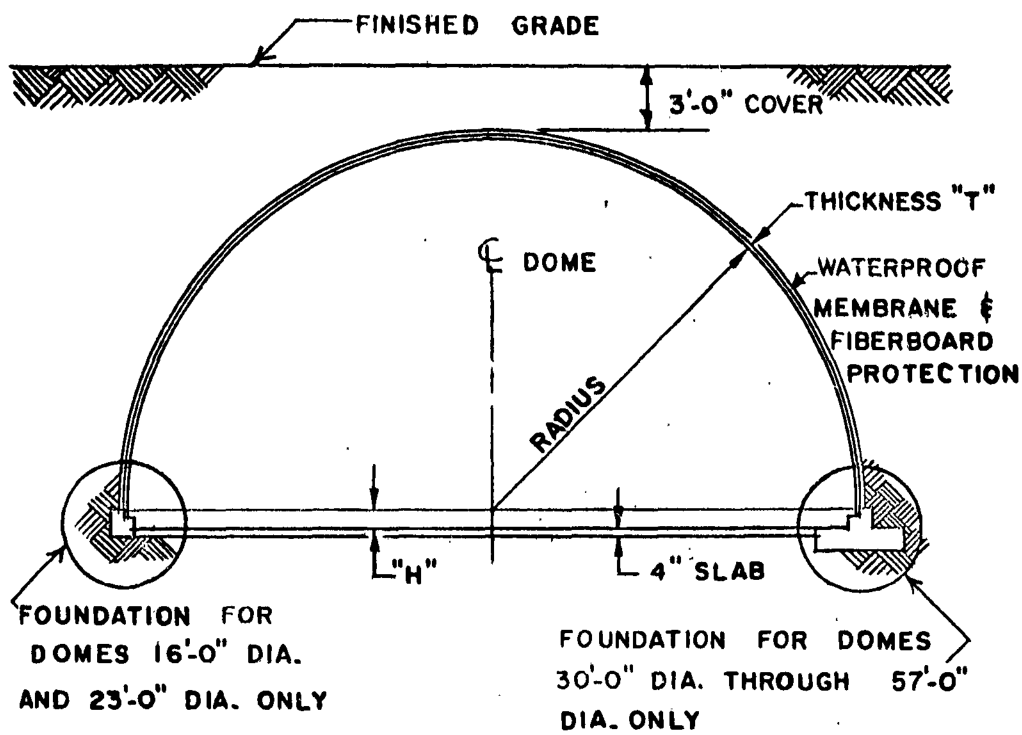
FIG.3.7



DIAMETER	THICKNESS "T"	"H"
16'–0"	3-1/2"	1'-0"
23'–0"	5"	1'-4"
30'–0"	7"	0'-8"
35'–0"	7-1/2"	0'-10"
44'–0"	10-1/2"	1'-2"
49'–0"	12"	1'-6"
57'–0"	1'-1-1/2"	1'-8"

35 PSI BURIED CONCRETE ARCH– CROSS-SECTION

FIG.3.8



DIAMETER	THICKNESS "T"	"H"	THEORETICAL THICKNESS
16'–0"	3"	1'–0"	0.8"
23'–0"	3"	1'–4"	1.1"
30'–0"	3"	0'–8"	1.5"
35'–0"	3"	0'–10"	1.8"
44'–0"	3"	1'–2"	2.3"
49'–0"	3"	1'–6"	2.5"
57'–0"	3"	1'–8"	3.0"

35 PSI BURIED CONCRETE DOME–CROSS-SECTION

FIG.3.9

SECTION 4

SPACE UTILIZATION

4.1 AN ANALYSIS OF BUNKING REQUIREMENTS

It became apparent, early in this study, that if the various shelter shapes and capacities were to be cost compared, we would need some means of determining the physical sizes of the configurations. That is, we would be faced with assigning areas for shelter functions both totally and on a per-capita basis.

One convenient way to do this is to size all configurations the same way using a reasonable area allotment per person. Several studies have been done this way with assigned values dependent somewhat upon knowledge gained from simulated testing, but mostly upon the researchers' opinions about adequacy. Generally, these studies have not established the possible performance differences due to variations in space utilization.

In this effort we have undertaken space utilization analyses for two basic reasons. First, even if equal accommodations are provided in the various shelter configurations, there may be space (and therefore, cost) differences directly chargeable to the nature of the structure (i.e. the shape). Second, the size and arrangement of habitability items may affect structural designs and therefore cost.

Among all items required for shelter living, sleeping facilities and their access appears to be the most important factor in allocating space. Some previous studies have proportioned bunk and aisle space as follows:

Study		
Dunlap	(16)	68%
NRDL	(1)	74%
A.I.R.	(14)	91%
BuDocks	(29)	93%

Since each of these studies was austere in terms of

facilities provided, these figures give a good indication of the importance of bunking. In this analysis we will attempt to define bunking performance in order to -

1 - Select a reasonable bunking scheme for lay-out purposes

2 - Determine area (cost) differences

3 - Determine the influence of scheduling on space requirements

4 - Define some features of a good bunking system

We caution that this is a limited study in that management and human factors have not been introduced. The various schemes selected for study may or may not be equal in <u>overall</u> performance.

4.1.1 BACKGROUND

Abstractly, there are a limited number of ways for people to use bare shelter space. That is, they may stand, sit or lie down. Providing equipment in the form of bunks and seats adds two more possibilities. Space requirements for each of these is shown on Figure 4.1. Data for the first four configurations are taken from Reference 30. Bunking dimensions are those recently developed in a concurrent study by the U.S. Army QM, R&E Command. Without considering access, space requirements range from 1.5 sq. ft./person to about 14 sq. ft./person with standing the most efficient way to use area and single-level bunking the least efficient.

Beyond these configurations there is the possibility of using tiered bunks. A comparison of area requirements between tiered bunking, sitting and standing (Figures 4.2 and 4.3) shows bunking is more efficient than seats when the tiers are 4 or more high and more efficient than standing when 10 or more high.

4.1.2 BUNKING SYSTEMS AND SCHEDULING

Although the above conclusions are valid, they may not be useable in a practical way. It is the opinion of many planners that tiering beyond 5 high may result in significant difficulties.

It may also be unreasonable to allocate space based on people standing* If these limitations are added to the analysis, the most efficient way to use space is to provide bunking only.

We recognize, however, that shelter performance may be overly restricted if the occupants must always remain in their bunks. That is, we would like to provide some relief, say, in the form of seating. Our minimum shelter would then include bunks and seats or space for seating. Now it is apparent that the type of bunking system selected and the way it is used will influence space requirements. An examination of some types of systems will show this. For illustrative purposes we have divided these into general categories - the fixed system, the demountable system and the convertible system and combinations of these. Descriptions and examples are as follows:

1 - We would describe a bunking system to be partially fixed if it or the space it occupies cannot be used for other purposes at other times or if it cannot be moved and used in other areas.

2 - A demountable system is one which can be readily broken down and stored in minimum space such that the area it occupied can be used for other purposes.

3 - In a convertible system, one or more of the tiered bunks can be rearranged to provide seating. In this study we have considered seating on one tier only.

Any of the above systems could be arranged for end or side loading. Various styles of bunks incorporating one or more of these features have been used in other studies. Some examples are shown on Figures 4.4 through 4.9.

The bunk shown on Figure 4.4 is that used in a recent simulated occupancy study by the American Institute for Research. (14) The bunk frames were made of angle irons with steel springs and wire lattice. The bunks were arranged in 3-high tiered units. Each unit is demountable to the extent that the bunk frames and uprights can be separated. If the center bunk is removed, each unit

* This may not be true if it means the difference between overcrowding or not having shelter.

will seat 4 persons. The system is free standing and can be end or side loaded.

The bunking system shown on Figures 4.5 and 4.6 was used by this office in a previous study. (12) This style of bunk is adaptable primarily to constant-headroom structures. It is fixed in the sense that it is not free-standing and cannot readily be used for seating. It is demountable. The system shown on Figure 4.7 is similar to the unit shown on Figure 4.6 except that it is arranged for end-loading.

Figures 4.8 and 4.9 illustrate a most recent design for low-cost sleeping facilities. It was developed by the Quartermaster R&E Command under contract to OCD (Project No. 1310). This unit is free-standing, designed for use in existing spaces where varieties of headrooms are encountered. The bunks can be arranged in units two wide by 3, 4 or 5 tiers high. Each module is approximately 4'-4" wide x 6'-4" long. Individual tiers are about 7", 27", 47", 67" and 87" above the floor level.

Frames and supports are of slotted angle iron with 1/4" plywood used as the sleeping surface. The bunk may be supplied with a urethane mattress. Each unit is completely demountable and convertible to seating arrangements.

Each of these systems is, in varying degrees, fixed, demountable for convertible and therefore may require different space allotments. Figure 4.10 shows a comparison between systems if both bunking and seating are required. The fixed system requires bunk space and seat space for everyone. The demountable scheme also requires a bunk and a seat but the sleeping area is available for seating. The convertible system requires no seating area if tiers are less than 5 high. The demountable system is always more efficient in terms of space required but may not be the most preferable in terms of cost or performance. It is not as easy to use as the convertible system and requires an additional piece of equipment (i.e. a seat)*. From these points of view it seems that a 4-high, side-loaded convertible system might be most attractive.

* Unless shelterees are willing to sit on the floor.

There is a possibility that variations in scheduling bunk time may influence space requirements and that this influence might not be the same for all configurations. There is also an interaction between scheduling and bunk system design. That is, demountable and convertible features become less valuable as bunk use increases. Figures 4.11 and 4.12* show the results of scheduling (or shifting for 5- and 3-high bunks). It is interesting to note, on an abstract basis, that with 3-high bunking an increase in the number of bunk shifts reduces area requirements whereas with 5-high bunking this trend reverses. With 4-high bunking, shifting has little effect. Another conclusion we might draw is that regardless of tiering the significant benefits are obtained in the range of 1 to 4 shifts.

To test these apparent effects, we decided to select some scheduling schemes, apply these to a configuration and calculate area requirements for each of the three bunking systems. The schemes selected for study are graphically shown on Figure 4.13. Scheme I is usually referred to as "cold bunking". Scheme II is 2-shift bunking and Scheme III is full "hot"bunking. Scheme IV is commonly called 2/3-hot bunking and is similar to the scheme suggested for consideration in a report by the American Institute for Research (14). The configuration used for evaluation is the circular arch. It was chosen because it possesses a certain degree of difficulty in space utilization. Three sizes of arches were selected as reasonable to house 100, 500 and 1,000 persons. Their dimensions are 16', 35' and 49' in diameter respectively with lengths calculated in accordance with bunking and seating requirements. Criteria used for layout purposes are as follows:

Bunk Dimensions	6'-4" long x 2'-2" wide
Maximum tiering	5 high
Lower bunk clearance	7"
Clearance between bunks	20"
Clearance between top bunk and ceiling	20"
Seat dimensions	18" x 18"

* In these figures, one bunk shift per cycle means one bunk per person and continuous use of bunks. Two shifts means half bunking, half seating and so on.

Minimum headroom for seating	4'-6"
Main aisles	4'-0"
Side aisles	2'-0"

In addition, we have assumed that fixed and demountable bunks may be end-loaded. Convertible bunks are required to be side-loaded.* Unit space data for the three arches are shown on Figures 4.14 through 4.18. The possible combinations total 36. The results of this investigation are given in Table 4.1.

4.1.3 SOME CONCLUSIONS

Within the limitations of this analysis, the following statements can be made for arch structures:

1 - Fixed bunking systems are optimum only when a continuous hot-bunking schedule is employed.

2 - Beyond this, demountable bunking is optimum. As shelter size increases, scheduling has little effect on space requirements when this system is used.

3 - The "cost" of a side-loading feature for continuous bunking is approximately 1/2 sq. ft. per person. (Difference between triple-shift fixed and triple-shift convertible).

4 - For single-shift or "cold" bunking, a demountable system may save as much as 1.7 sq. ft. per person, but this apparent saving might be offset by the cost of providing seats.

For the remainder of this study we have decided to base area requirements on the use of convertible bunks arranged for single-shift sleeping. Although this is not optimum, it may be more reasonable to use than some other system for several reasons. First, because side-loading has become preferable (31) to end-loading. Second because convertible

* If the bunks are reoriented after each shift they could be end-loaded. We have not done this.

TABLE 4.1

COMPARISON OF BUNKING SYSTEMS

APPLIED TO ARCH CONFIGURATIONS
(AREAS FOR BUNKING & SEATING ONLY)

BUNK TYPE	BUNKING SCHEDULE	BASIC AREA PER PERSON 16' ARCH (100 cap.)	35' ARCH (500 Cap.)	49' ARCH (1000 cap.)
Fixed+	Single Shift	9.8	9.3	9.7
"	Double Shift	7.5	7.0	6.9
"	Triple Shift	5.1	4.6	4.7
"	Two-Thirds Shift	8.4	7.7	7.6
Demountable+	Single Shift	8.3	4.9	4.6
"	Double Shift	5.2	4.8	4.7
"	Triple Shift	*	*	*
"	Two-Thirds Shift	5.7	5.1	4.7
Convertible	Single Shift	6.9	6.7	6.3
"	Double Shift	6.1	5.6	4.9
" (+)	Triple Shift	5.8	5.0	5.2
"	Two-Thirds Shift	7.5	6.1	5.4

* This Combination is not possible since the bunks are in continuous use.

\+ End Loading

(+) This combination is included to show the effect of the side loading feature

bunking systems might be easier to use than demountable systems. Third, because they have "built-in" seating. And fourth, because designing for continuous bunking may not allow a margin of safety in terms of overcrowding.

As an example of the last point, consider a typical 100-person arch arranged with convertible bunks and programmed for single-shift sleeping (Figure 4.19). If the interior configuration is rearranged to provide for continuous end-loaded bunking, it will accommodate 80% more shelterees. Practically, this is accomplished by discarding 2/3 of the bunks and using the excess area for seating* (see Figure 4.20). If one is really interested in providing an overcrowding capability, the same shelter might be designed with about 50% more area (Figure 4.21) which would result in a 200% overload capability (Figure 4.22). This same sort of analysis can be applied across the whole spectrum of possible bunking schemes and schedules. Using the single-shift convertible system as a base, the changes in population that might be expected with other arrangements (for arch configurations) are shown in Table 4.2.

During this investigation of bunking methods and scheduling some attributes of a good bunking system have become apparent. Briefly, these are to be:

1 - Capable of being re-positioned (free-standing)
2 - Demountable
3 - Convertible to seating
4 - Easy to use

A bunking system which incorporates all of these features would afford a high degree of flexibility of use in any shelter configuration.

4.2 OPTIMUM BAY FOR RECTANGULAR STRUCTURES

For a particular capacity and overpressure rating, the optimum rectangular configuration is a function of bay size (column spacing), ceiling height and aspect ratio. From struc-

* On the floor if seating for the overcrowding possibility is not initially included.

TABLE 4.2

ESTIMATED OVERLOAD CAPABILITY FACTORS

FOR ARCH CONFIGURATIONS

Fixed - 3 Shifts	1.30
Demountable - 2 Shift	1.26
Demountable - 2/3 Shift	1.21
Convertible - 3 Shift	1.20
Convertible - 2 Shift	1.17
Demountable - 1 Shift	1.11
Convertible - 2/3 Shift	1.05
Convertible - 1 Shift	1.00 Base
Fixed - 2 Shift	.92
Fixed - 2/3 Shift	.80
Fixed - 1 Shift	.55

tural computations, we have found that minimum costs are associated with small bay sizes and square (in plan) structures. It remains now to determine the least possible bay size and headroom consistent with efficient utilization of space.

4.2.1 ADAPABILITY

Since most shelter area is used for bunking, it seems desirable to plan column spacing on adapability to the bunk system. For our purposes, we have chosen the Quartermaster-type bunking module with dimensions 6'-4" long by 4'-4" wide. The minimum bay sizes which will accommodate this system are 6'-4" by 7'-0" and 6'-4" square depending on whether or not column encroachment on a 2' aisle is permissable (Figure 4.23). If such is the case, the square bay will result in an area, and therefore roof system cost, saving of about 10%. The rectangular structures developed hereafter reflect these cost savings.

4.2.2 OPTIMUM HEADROOM

Minimum practical headroom will allow 4-high tiered bunking; and if the performance limit is taken at 5-high, the optimum headroom can be established by a comparison between these two arrangements. This comparison was undertaken for the three rectangular shelter sizes (100, 500 and 1000) designed for 35 and 60 psi (See Appendix B-1).

Results indicate that within the criteria limits, 4-high tiering is optimum. There is an apparent trend which indicates that for larger units this may not be true.

4.3 ARCH CONFIGURATIONS

Arch structures present somewhat of a complex problem in terms of space utilization in that there are many possible combinations of diameters, lengths, interior decking and tiering of bunks which can result in 100, 500-or 1000-person shelter units. A separate investigation was undertaken for the various arch diameters to determine the approximate cost differences for the various combinations. The basic cost data used for corrugated steel arches and reinforced concrete arches are shown on Figures 4.24 and 4.25. The results of the analysis are given in Appendix B-2.

From this cost information, we can conclude the following:

1 - The small concrete arch configuration (16' diameter in this analysis) will result in minimum cost for all three capacities. For small steel arches this result is not clear "across-the-board".

2 - Beyond this, reasonable arch configurations for 500 persons and 1,000 persons can be represented by the 35' arch and the 49' arch, steel or concrete, arranged mainly with 4-high bunking.

4.4 DOME CONFIGURATIONS

The dome configuration presents a most difficult space utilization problem and tedious trial and error solutions are required to determine the optimum diameter for a given capacity. Basic cost data for reinforced concrete domes are given on Figure 4.26. With this data and space requirements as established in this section and others, reinforced concrete domes for the three capacities were selected and costed. The results are given in Section 7.

(text continued on page 85.)

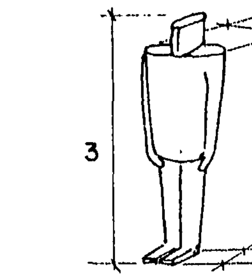
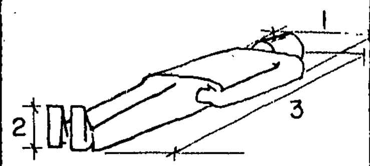
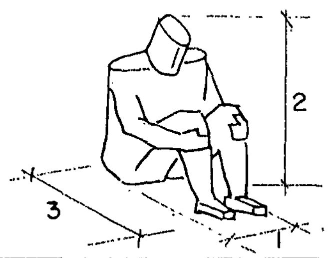
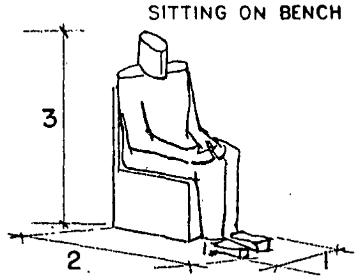
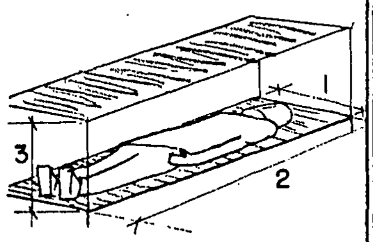
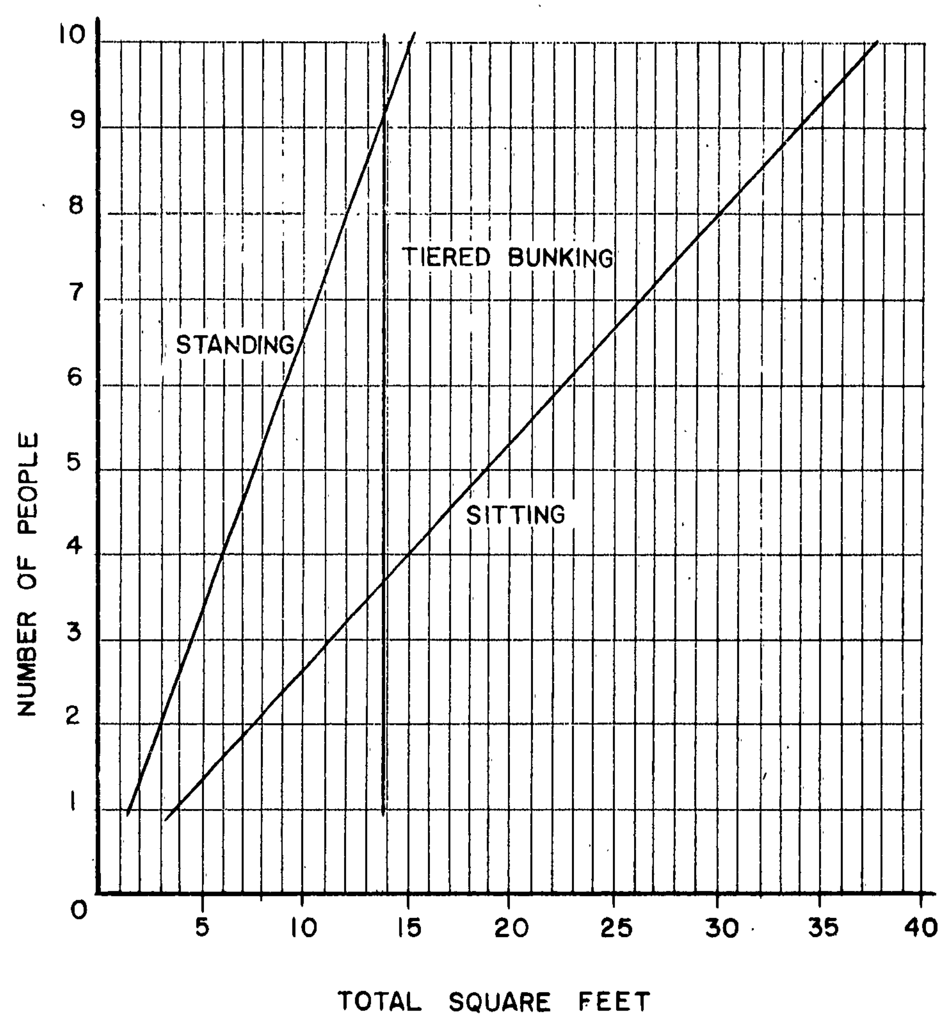
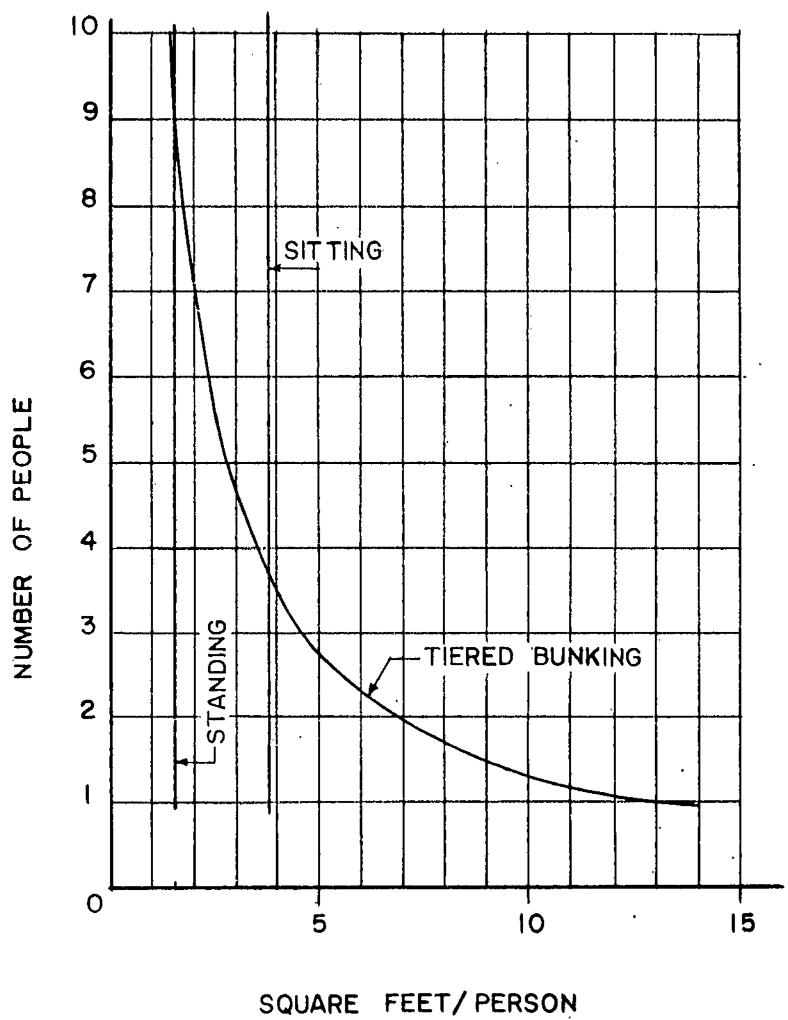
	DIMENSION NUMBER 1	2	3	SQ.FT.	CU.FT.
 STANDING	1.5'	1.0'	6.0'	1.5	9.0
LYING DOWN 	1.5'	1.0'	6.0'	9.0	9.0
SITTING ON FLOOR 	1.5'	3.0'	3.0'	4.5	13.5
SITTING ON BENCH 	1.5'	2.5'	4.5'	3.75	16.875
 LYING IN A BUNK	2.2'	6.3'	1.7'	13.86	23.56

FIG. 4.1



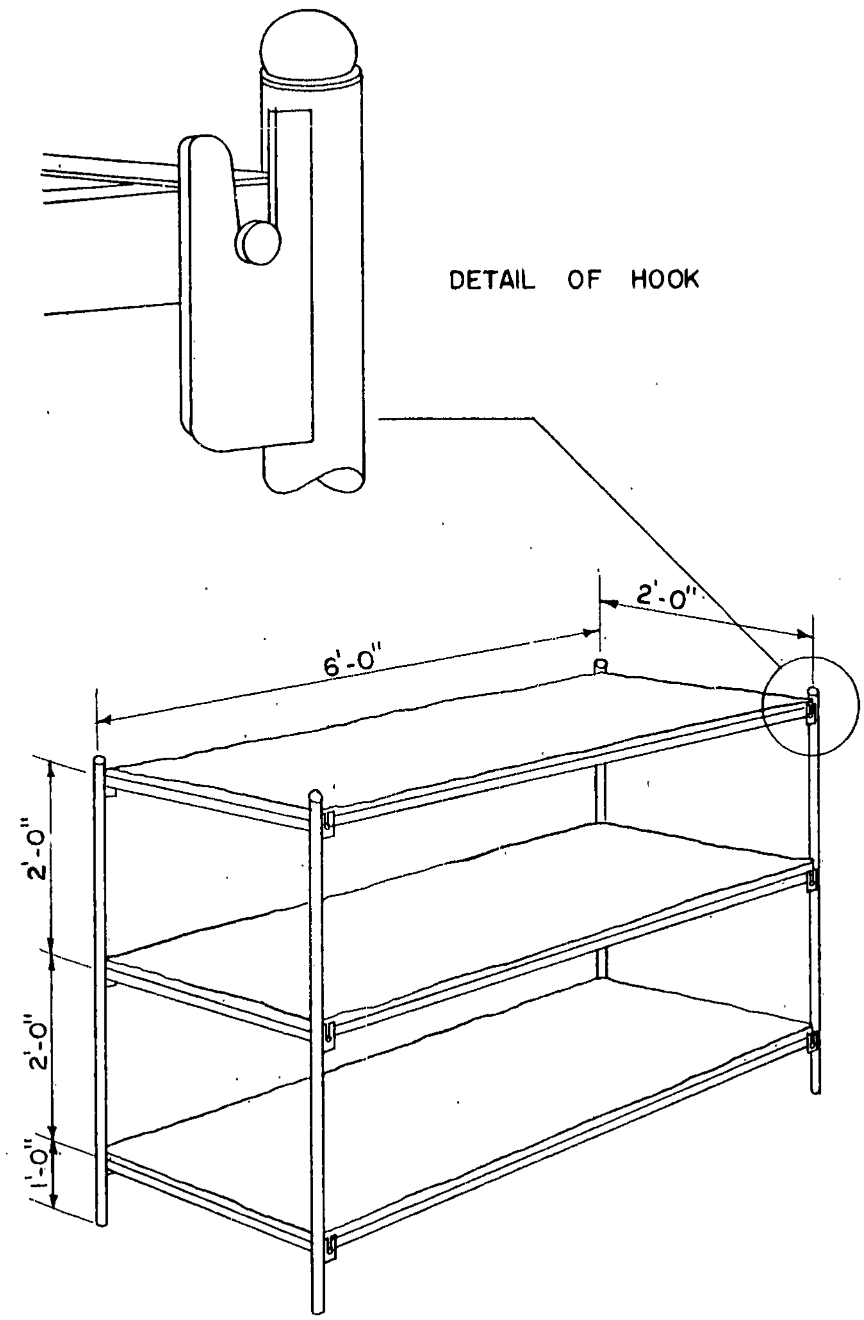
BASIC AREAS REQUIRED EXCLUDING AISLE SPACE

FIG. 4.2

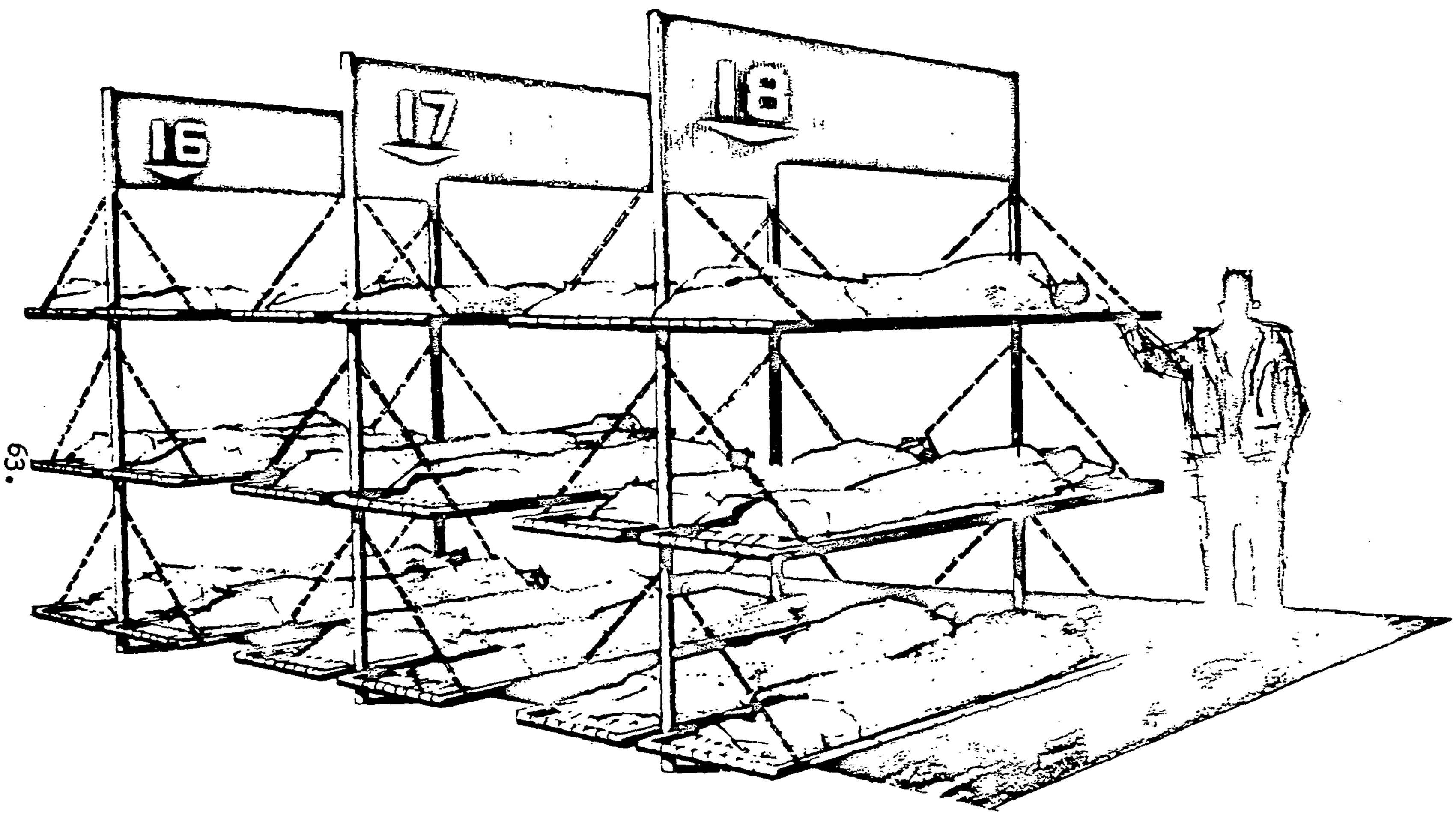


BASIC AREAS REQUIRED EXCLUDING AISLE SPACE

FIG. 4.3

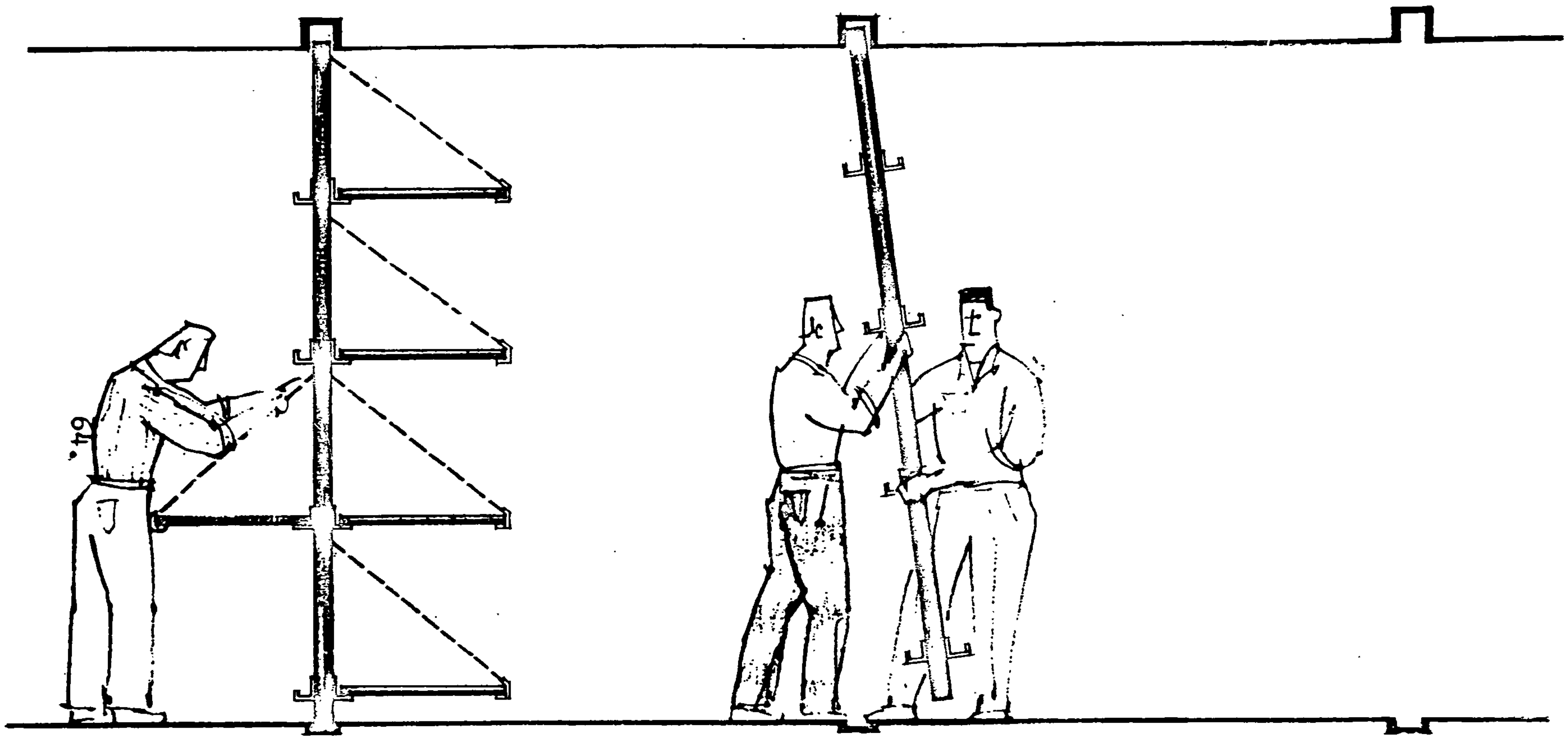


BUNK USED BY THE
AMERICAN INSTITUTE FOR RESEARCH
FIG. 4.4

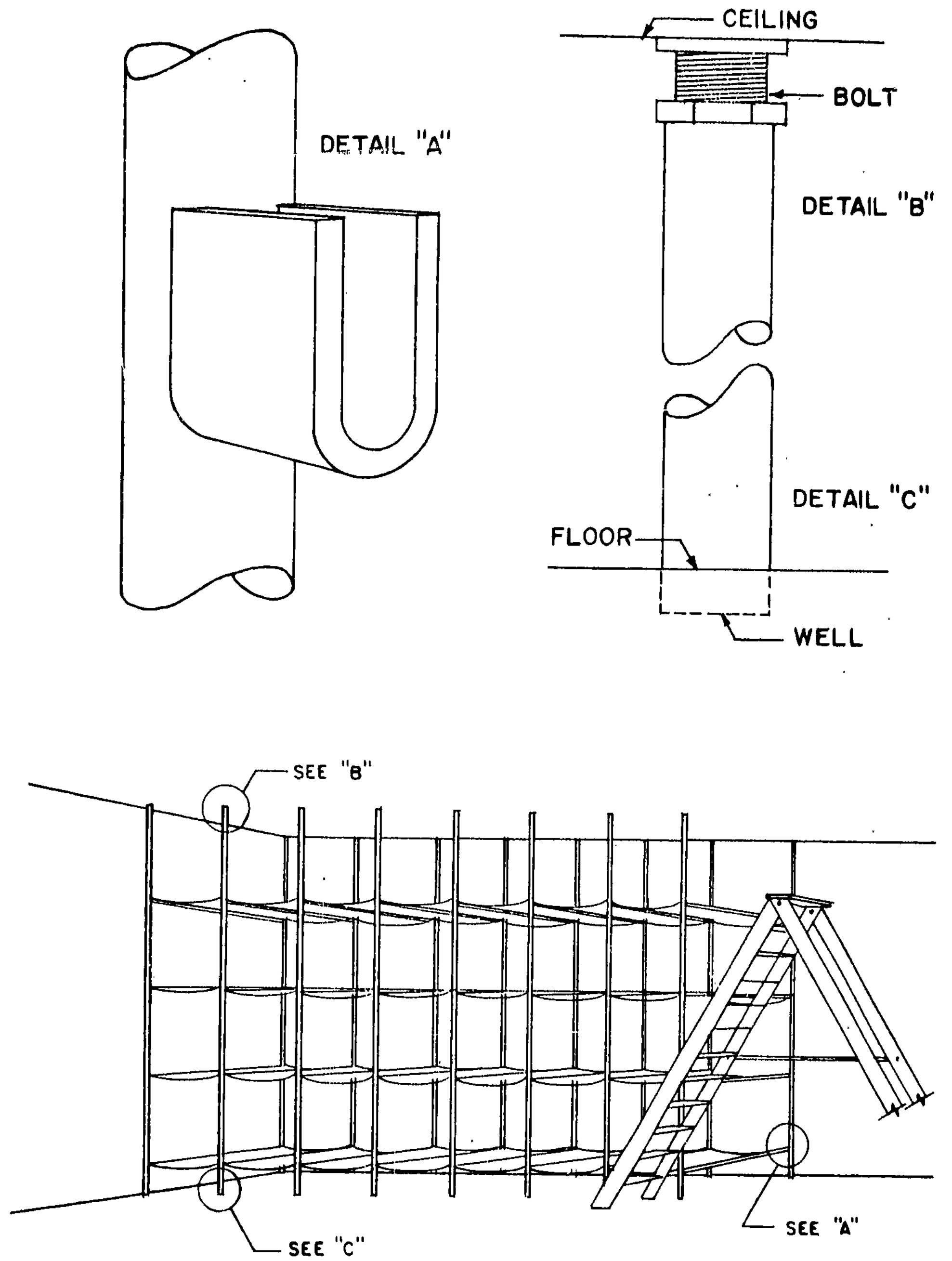


SKETCH OF BUNKING AREA
TAKEN FROM REPORT BY G.B. PANERO
FOR O.C.D.M. JAN. 1959

FIG. 4.5



POSSIBLE DEMOUNTABLE BUNK ARRANGEMENT
(G.B.P. O.C.D.M. REPORT JAN. 1959)
FIG. 4.6

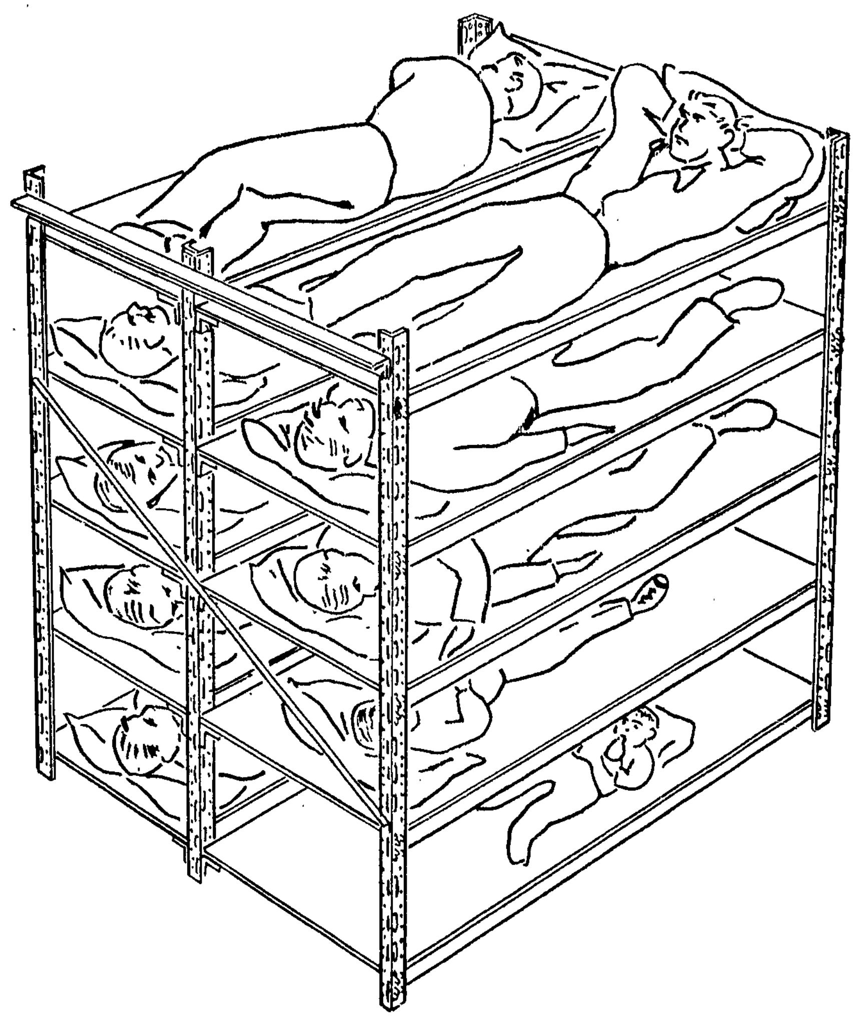


CONTINUOUS SHEETING — END LOADED

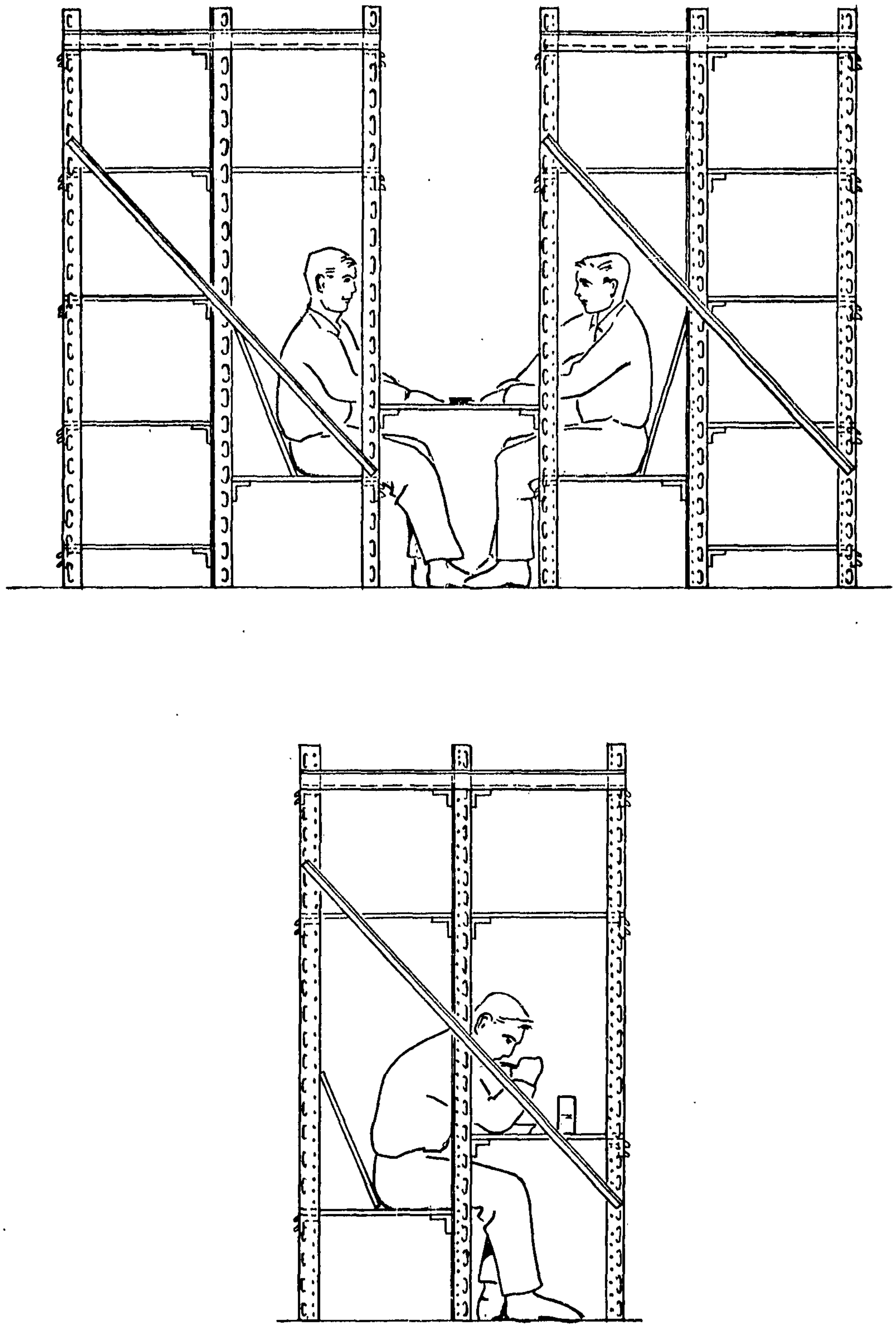
BUNKING SCHEME

(USNRDL-TYPE)

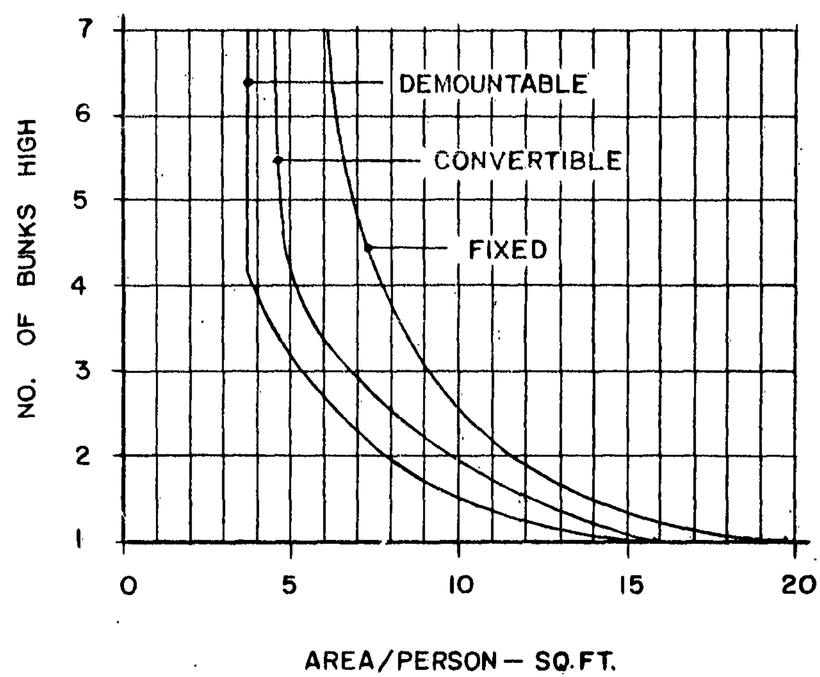
FIG.4.7



QUARTERMASTER TYPE BUNK
(ARRANGED FOR SLEEPING)
FIG. 4.8



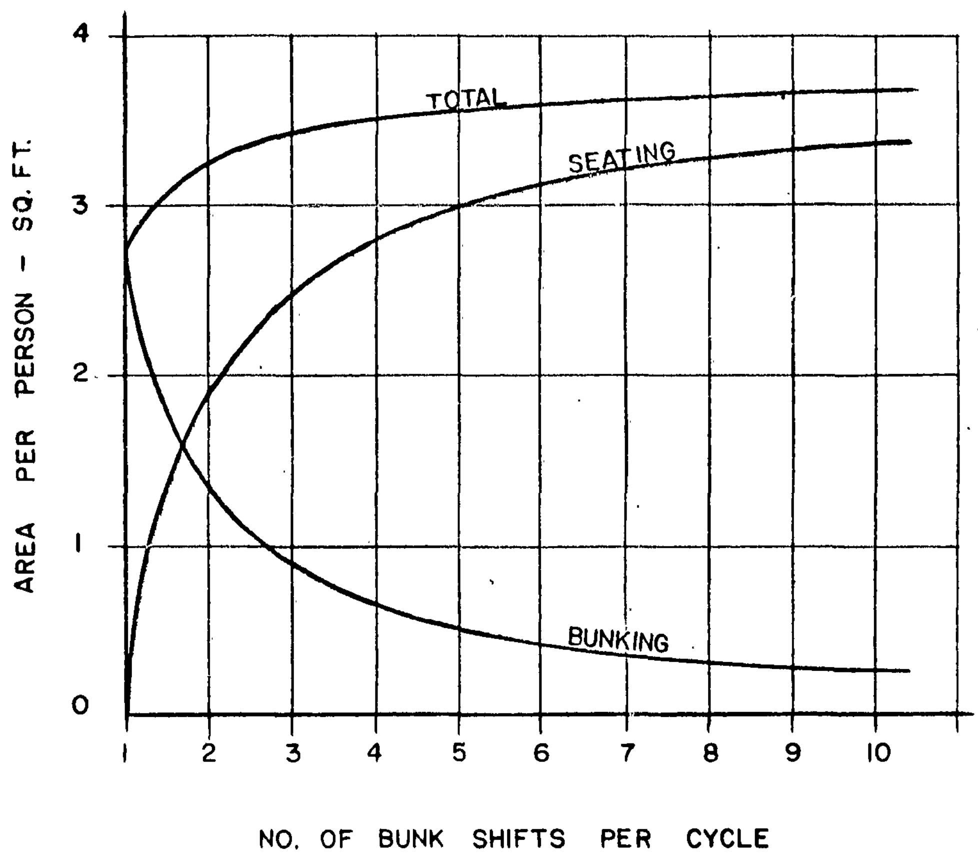
QUARTERMASTER TYPE BUNK
(ARRANGED FOR SEATING)
FIG. 4.9



AREA COMPARISON OF BUNKING SYSTEMS

(NO SHIFTING)

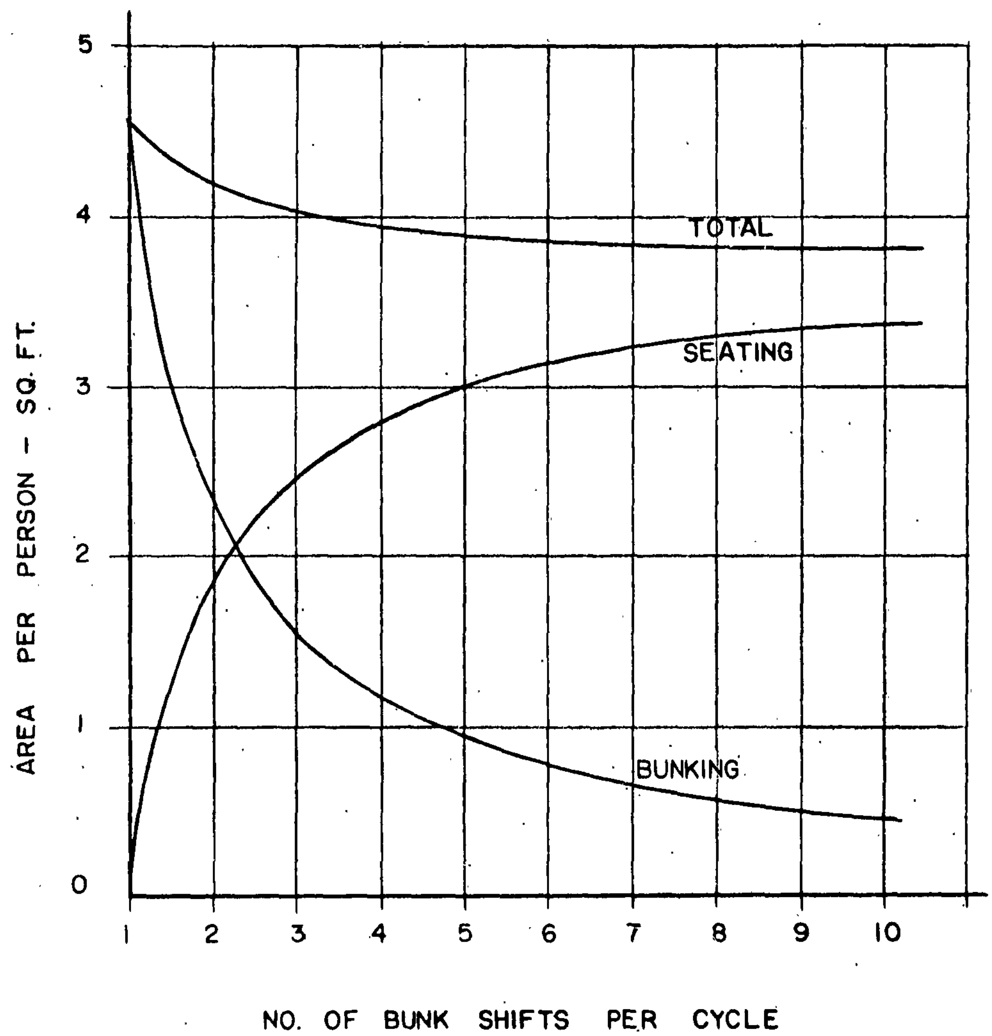
FIG. 4.10



EFFECT OF SHIFTING

(5 HIGH BUNKS EXCLUDING AISLE SPACE)

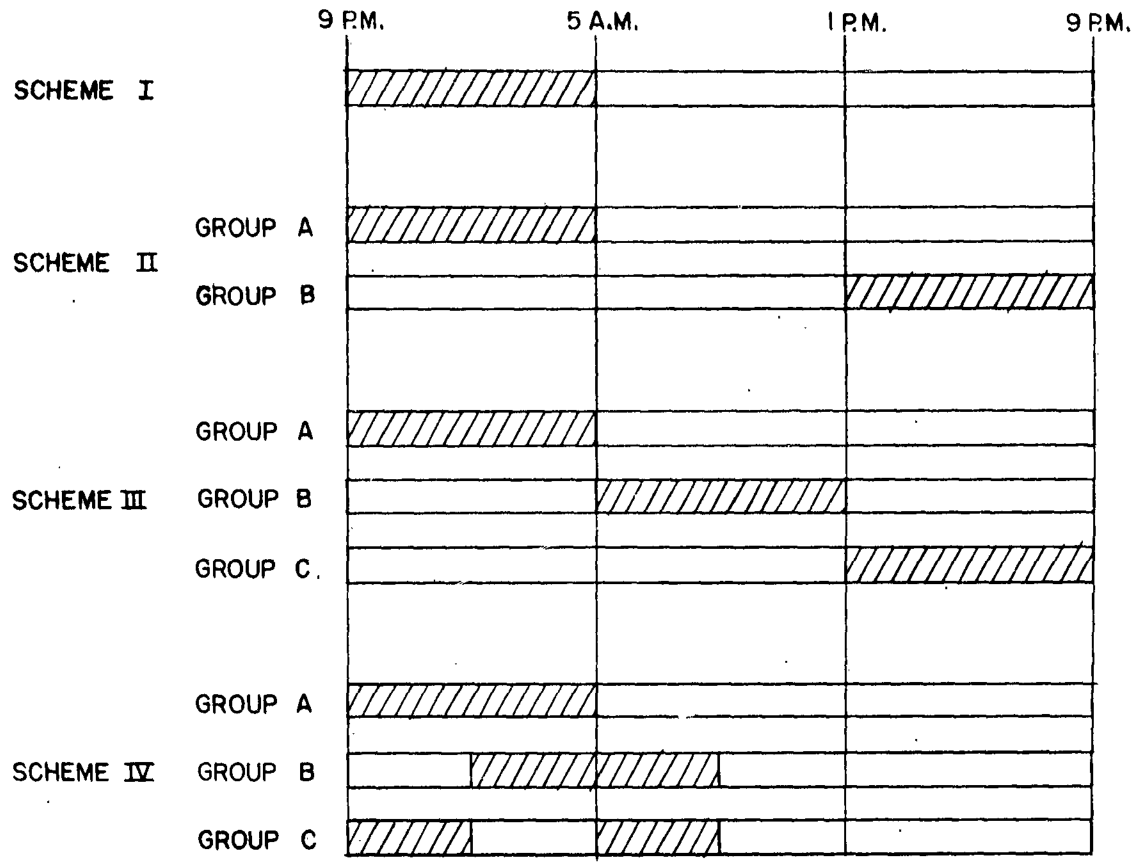
FIG. 4.11



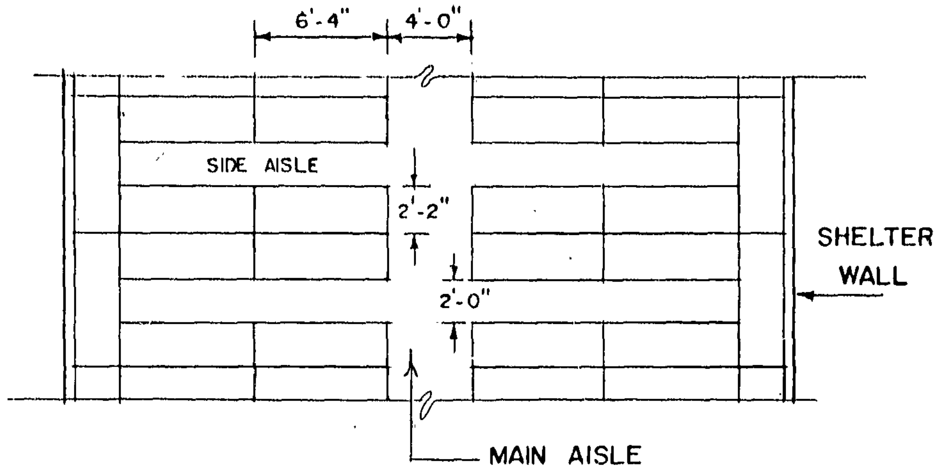
EFFECT OF SHIFTING

(3 HIGH BUNKS EXCLUDING AISLE SPACE)

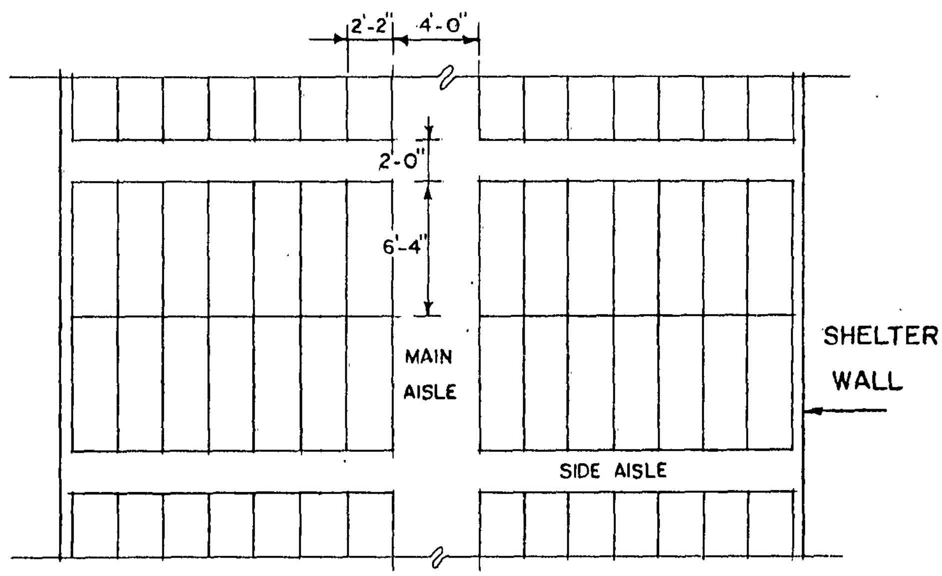
FIG. 4.12



POSSIBLE ALTERNATE BUNKING SCHEDULES
(8 HOURS BUNK TIME PER PERSON)
FIG.4.13

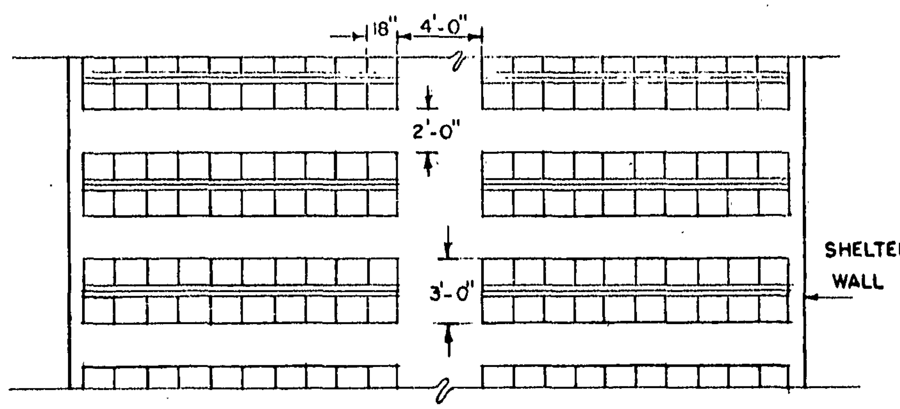


TYPICAL SIDE LOADED BUNKING ARRANGEMENT



TYPICAL END LOADED BUNKING ARRANGEMENT

FIG. 4.14



TYPICAL SEATING ARRANGEMENT

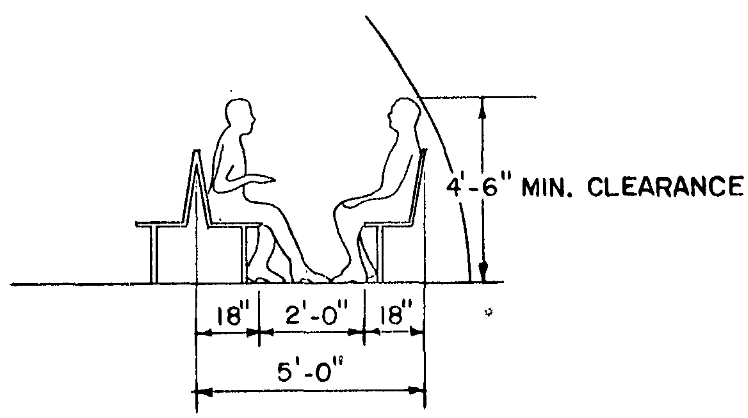
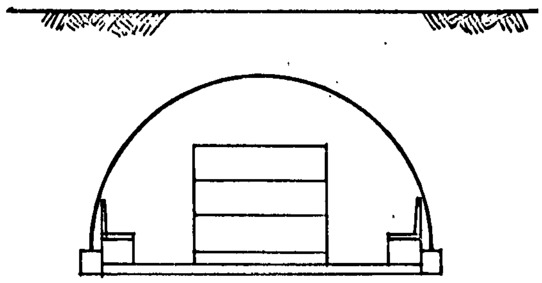
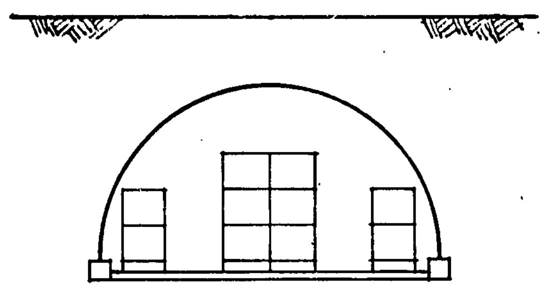


FIG. 4.15



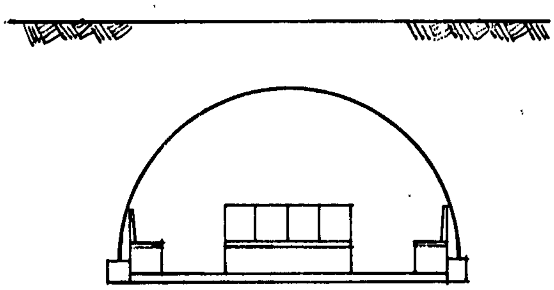
END LOADED BUNKS & CONTINUOUS SEATING

1.8 BUNKS / FT. 1.3 SEATS / FT.



SIDE LOADED BUNKS

2.2 BUNKS / FT. 2.5 BUNK SEATS / FT.



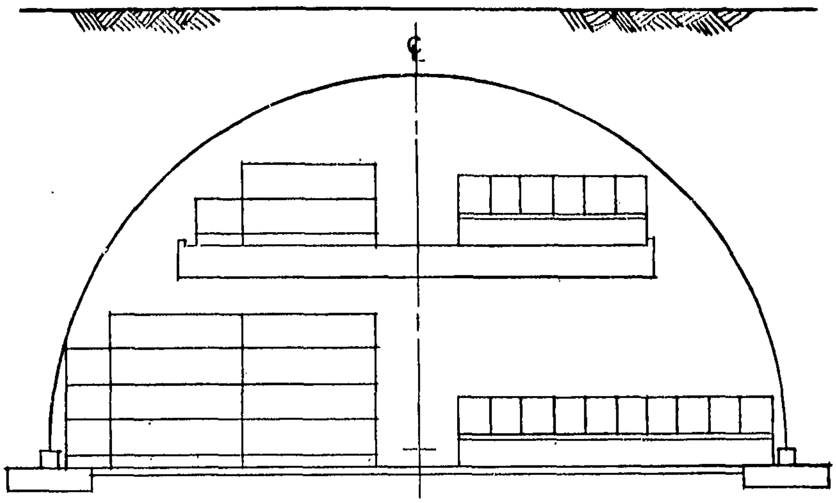
SEATING

2.9 SEATS / FT.

16'-0" DIAMETER ARCH

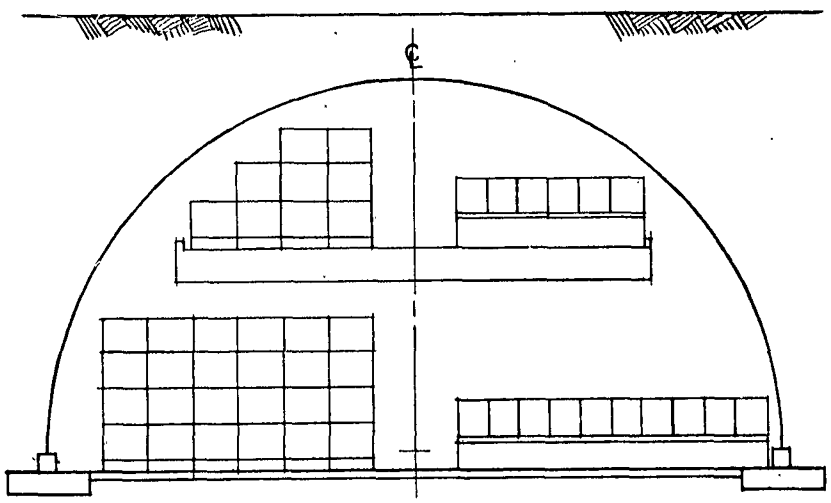
BASIC BUNKING & SEATING ARRANGEMENTS

FIG. 4.16



SIDE LOADED BUNKS & SEATING

10.1 BUNKS / FT. 7.6 BUNK SEATS/FT. 12.8 SEAT/FT.

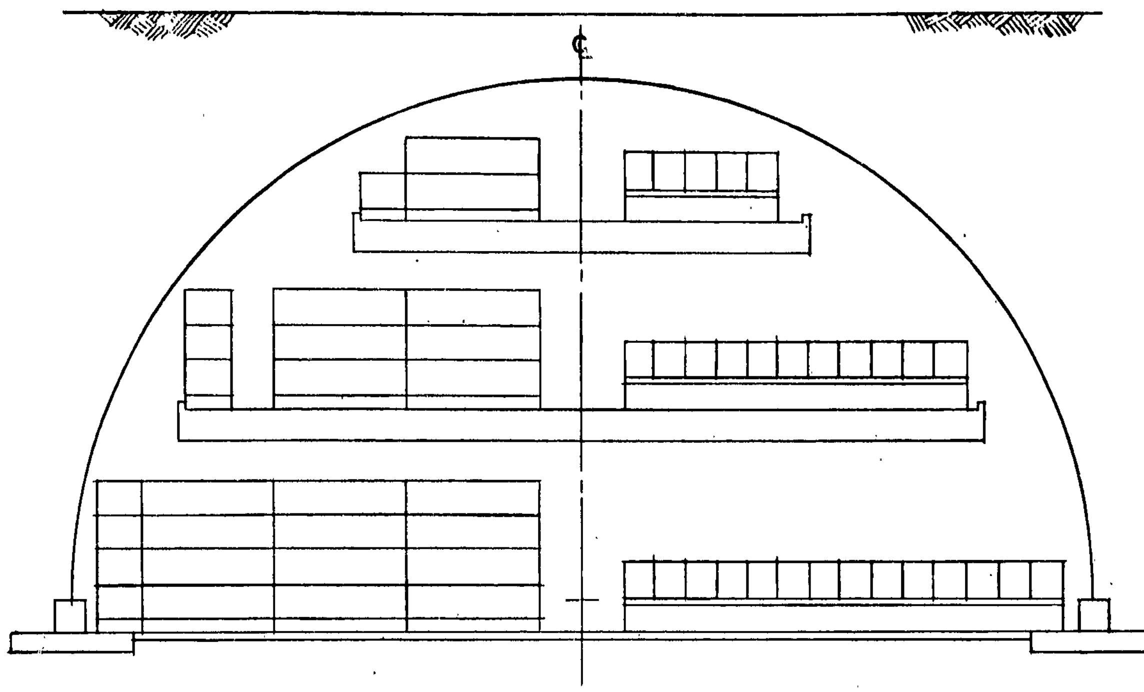


END LOADED BUNKS & SEATING

13.6 BUNKS / FT. 12.8 SEATS/FT.

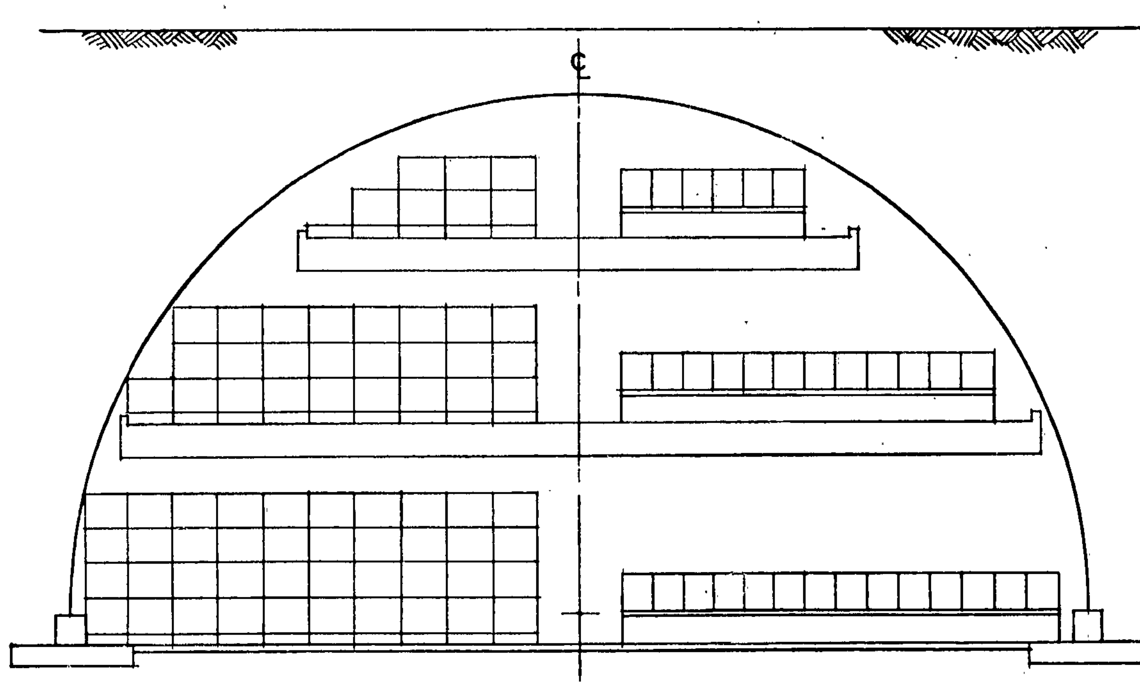
35'-0" DIAMETER ARCH

FIG. 4.17



SIDE LOADED BUNKS & SEATING

19.9 BUNKS/FT. 16.4 BUNK SEATS/FT. 24.0 SEATS/FT.

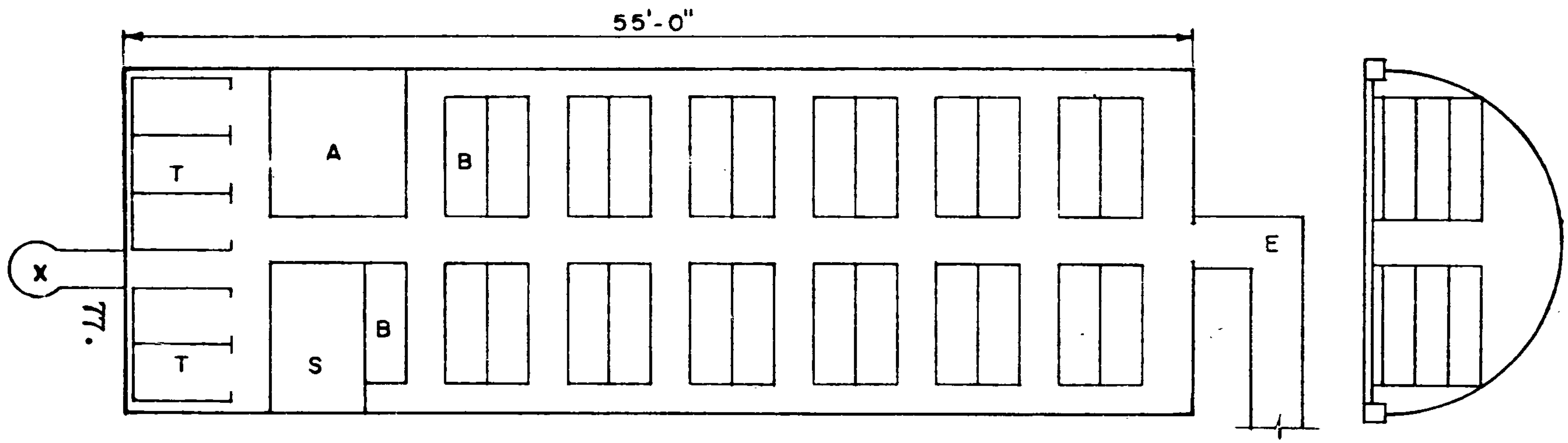


END LOADED BUNKS & SEATING

26.2 BUNKS/FT. 25.6 SEATS/FT.

49'-0" DIAMETER ARCH

FIG. 4.18



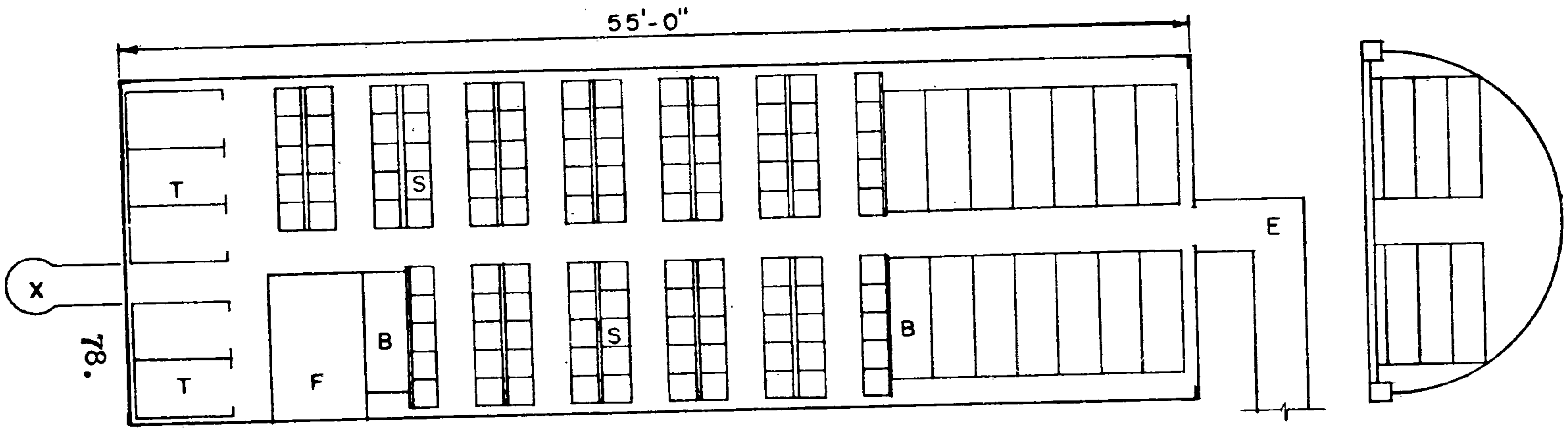
18'-0" DIA. ARCH

LEGEND

E – ENTRANCE
A – ADMINISTRATION
X – EXIT
B – BUNKS
S – STORAGE
T – TOILETS

9.35 SQ.FT./PERSON

BASIC ARCH
FIG. 4.19



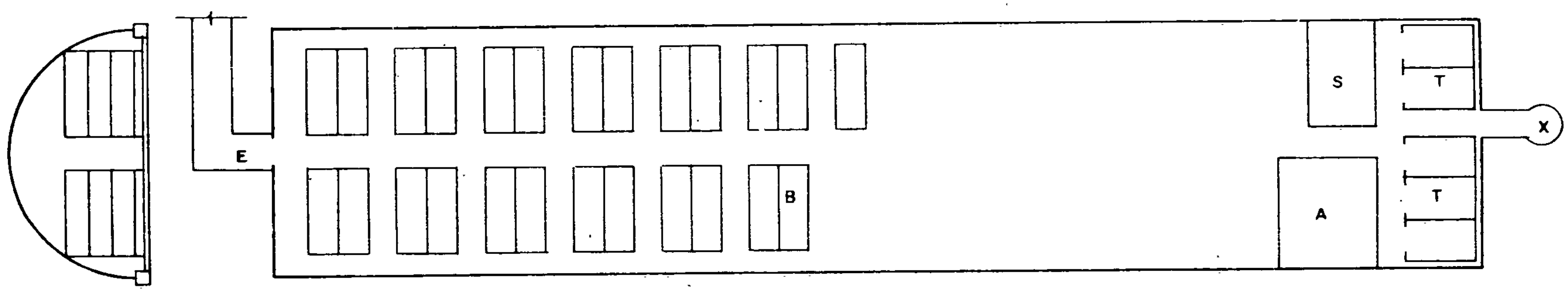
18'-0" DIA. ARCH

5.19 SQ.FT./PERSON

LEGEND

E – ENTRANCE
X – EXIT
T – TOILETS
F – STORAGE
S – SEATS
B – BUNKS

BASIC ARCH
(80% OVERLOAD)
FIG. 4.20



18'-0" DIA. ARCH

14.62 SQ.FT./PERSON

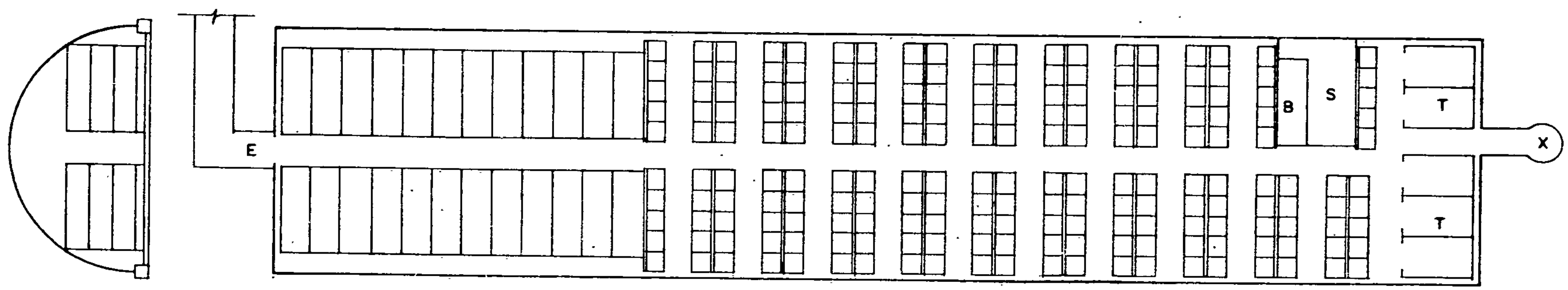
LEGEND

E – ENTRANCE
X – EXIT
B – BUNKS
S – STORAGE
T – TOILETS
A – ADMINISTRATION

200% OVERLOAD DESIGN

(BASIC CONFIGURATION)

FIG.4.21



18'-0" DIA. ARCH

4.87 SQ.FT./PERSON

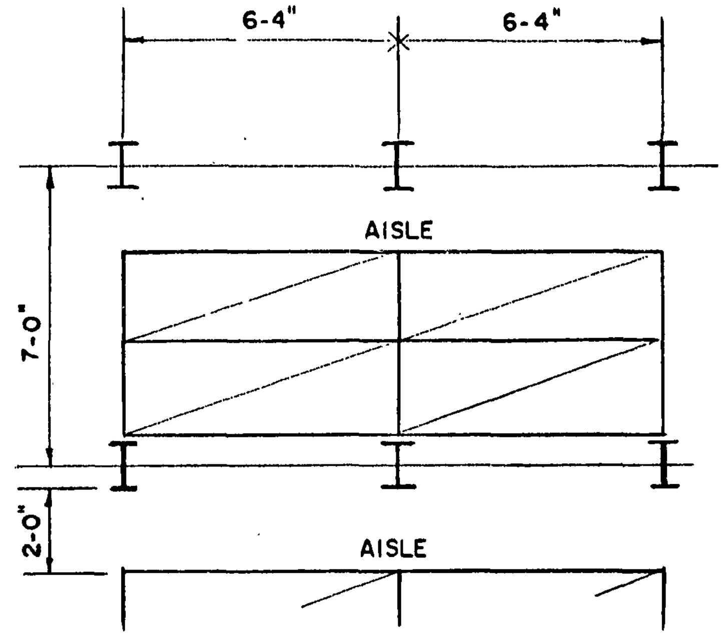
LEGEND

E - ENTRANCE
X - EXIT
B - BUNK
S - STORAGE
T - TOILETS

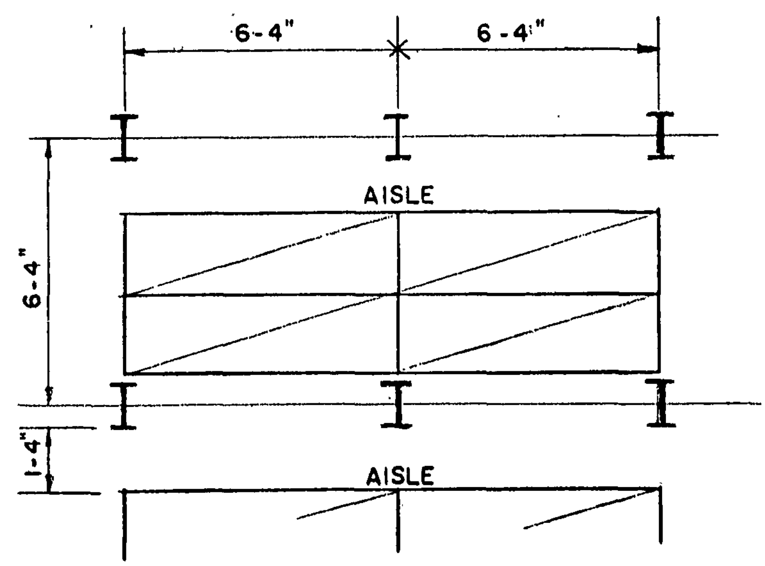
200% OVERLOAD DESIGN

(OVERLOAD CONFIGURATION)

FIG. 4.22

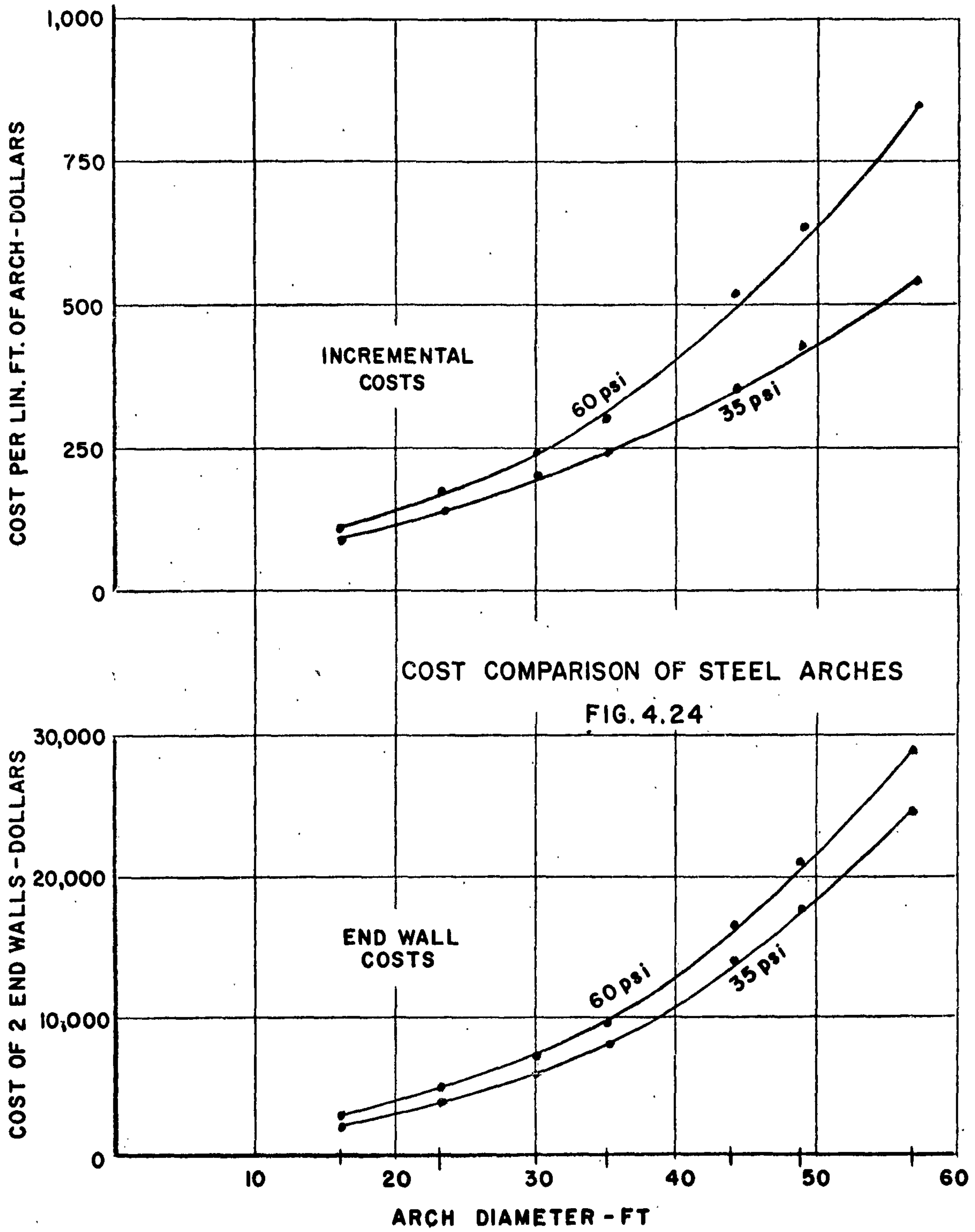


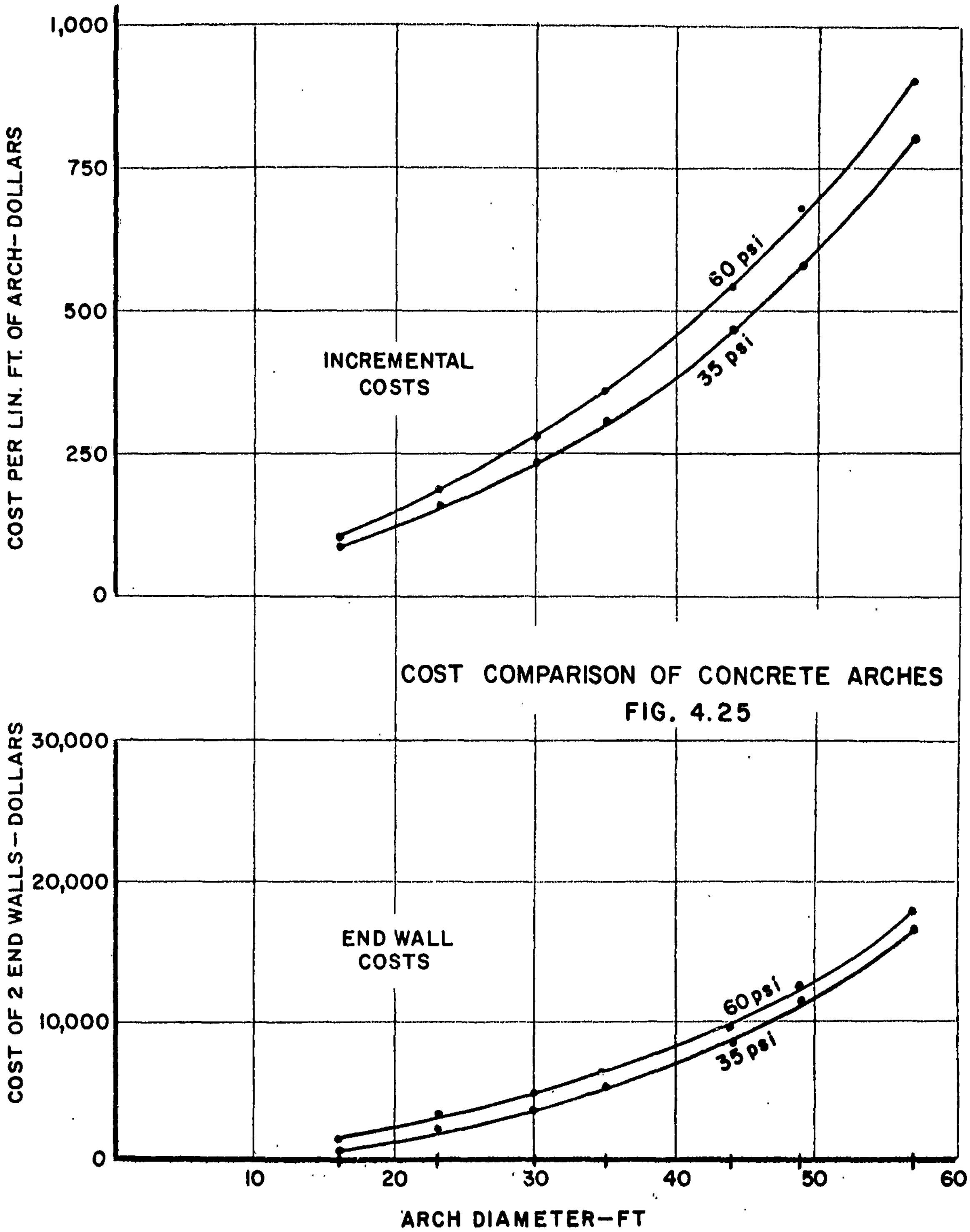
BUNK BAY WITH NO AISLE ENCROACHMENT BY COLUMNS



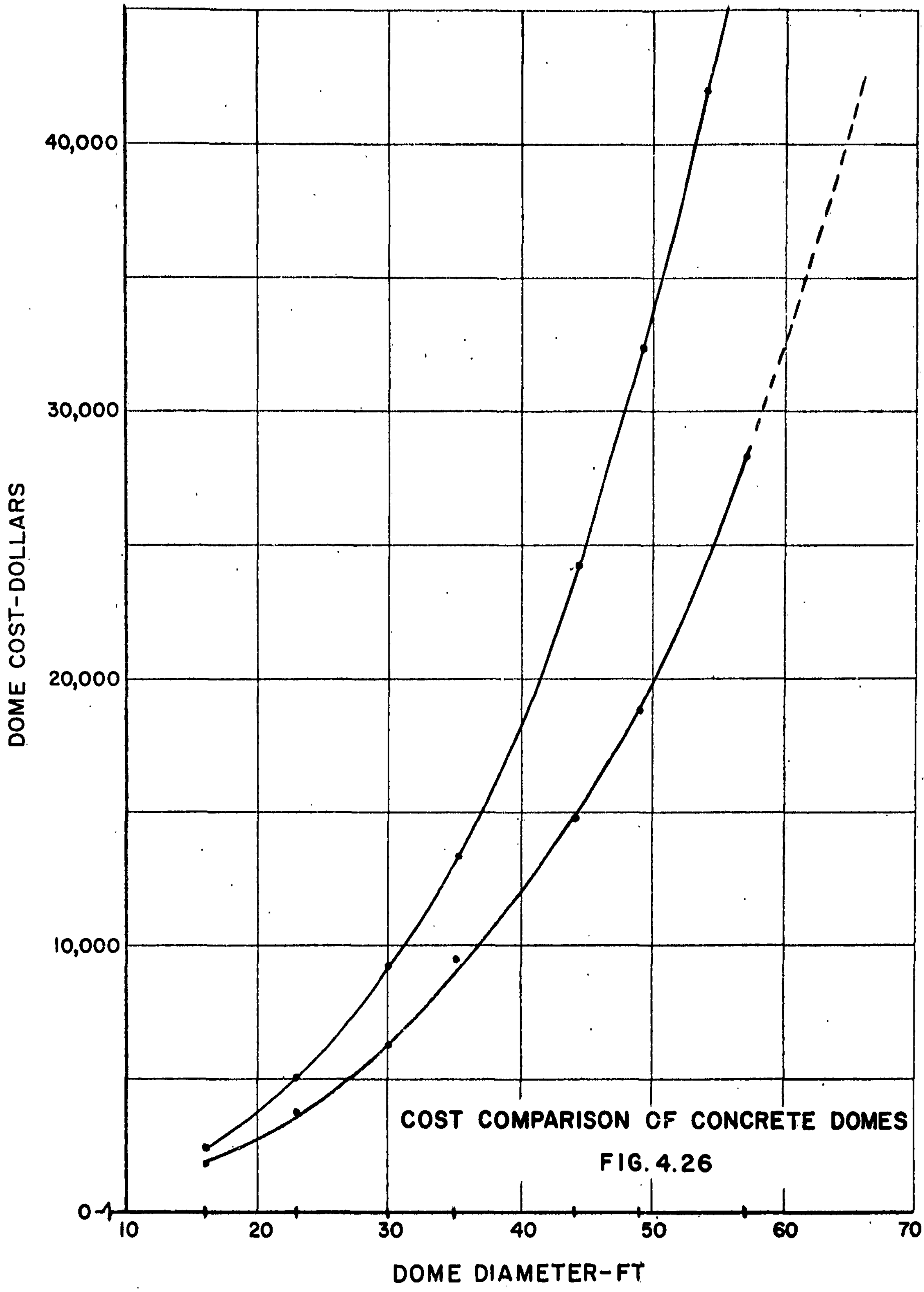
BUNK BAY WITH REDUCED AISLE AT COLUMNS

FIG. 4.23


1,000
750
500
250
0
COST PER LIN. FT. OF ARCH-DOLLARS
INCREMENTAL COSTS
60 psi
35 psi
COST COMPARISON OF STEEL ARCHES
FIG. 4.24
30,000
20,000
10,000
0
COST OF 2 END WALLS-DOLLARS
END WALL COSTS
60 psi
35 psi
10
20
30
40
50
60
ARCH DIAMETER - FT



COST COMPARISON OF CONCRETE ARCHES
FIG. 4.25



COST COMPARISON OF CONCRETE DOMES

FIG. 4.26

SECTION 5

ENTRANCE PACKAGES

5.1 INTRODUCTION

This section deals with the influence of entrance and exit on configuration. That is, to say, entrance and exit configurations have been evaluated and selections designed to a point required for costing.

The entrance and the exit are considered the two facets of an entrance package rather than as separate shelter components. This is because they are closely related or interdependent as the capabilities designed into one influence the other.

Entrance packages for shelters must be designed to perform certain functions:

1 - Low rate ingress and egress for peacetime maintenance. The package must be usable on a repetitive basis for small numbers of security or housekeeping personnel to enter and leave the shelter by more or less normal methods without deterioration or reduction of its capabilities for use by shelterees.

2 - High rate ingress at pre-attack (pre-blast and pre-fallout) time. The entrance must be of sufficient capacity to admit the required number of persons per minute to fill the shelter at the time of pre-attack warning. If the shelter itself can survive a given blast pressure then the entrance must in addition be capable of surviving the same blast pressure and then providing quick entry. This would be for a potential shelter population that had survived, though unable to reach the shelter before the blast, but did not have fallout protection. These people could conceivably quickly reach and enter a shelter before the fallout arrived.

3 - Low rate egress and ingress in a post-attack period. This would be for exploratory and decontamination teams plus final evacuation.

In addition, entrance packages might be used for other functions such as: housing mechanical-electrical equipment; settling intake air particles; discharging air; and storing food or equipment. Using entrances for these purposes depends upon the economics of alternatives beyond their basic function as entrances.

Basic criteria for entry and egress are given in Section 2.2.4.

5.2 TYPES OF ENTRANCES

The basic manual or non-mechanical methods of entering a shelter are jumping, sliding, climbing, or walking, by means of a vertical well, a chute or pole, a ladder, or a ramp or stairs, respectively. Mechanical means such as moving ramps, escalators and elevators have not been considered.

5.2.1 JUMP

Entrance to a shelter by jumping from the ground surface down a well or shaft is probably the minimum-cost method. The shaft walls and landing point would require careful padding to avoid injury and multiple stages (second or third jump from intermediate landings) might be necessary. This method is uninteresting because; it is a one-way method; the tendency for pile-ups at the landing point would be strong as there would be a serious problem of regulating flow to allow people to compose themselves and move off the landing point; there would be a high injury probability regardless of the precautions taken.

5.2.2 SLIDE

Use of the firepole to slide into the shelter is probably safer and more reasonable than the "jump" method but it too is considered unusable in spite of the relatively low cost, because of the same danger of pile-up and injury at the landing point at shelter level and the fact that it is a one-way access.

The fire escape-type chute is a much safer slide than the

pole type in that lower velocities are involved and the physical demands on the user are much less. There is still cause for serious concern regarding the ability of people to quickly move off the discharge point at the end of the slide. Any delay at this point would probably cause a pile-up and possible injury. This again is a one-way access and the cost of compensatory exits must be added to the chute cost. The total slide entrance package is estimated to be in the same cost range as stairs.

5.2.3 LADDERS

The feasible rate of entry to a shelter by climbing down ladders is much less than what is required for even the 100-man shelter and becomes even less reasonable as the larger shelters are considered. It does, however, appear to be the least expensive, most reasonable method of providing the exit portion of the package.

5.2.4 RAMPS

The pedestrian ramp is probably the safest means of entrance to a shelter. The rate of entry is simply a function of the ramp width; the danger of injury from stumbling, falling and pile-up is less than for jumps, slides, ladders and stairs. In addition it provides two-way access. The cost per linear foot of covered ramps is estimated to be slightly (approximately 16%) less than that of stairs. However, inasmuch as a slope of 100% can be used for stairs while a maximum slope for ramps is approximately 16%, ramp entrances are considerably more expensive than stair entrances. Open ramps would be more expensive than covered ramps because of the additional wall heights required to maintain the excavation cross section. They would create drainage and in many areas snow removal problems.

They have the additional disadvantage that they would be unusable as settling chambers for intake air.

5.2.5 STAIRS

With the exception of the ramp, entry by stairs is the only method that can reasonably meet the rate-of-entry requirements. While it is perhaps slightly less safe, it is a recognized means of economical mass movement. If it were necessary to descend

to considerable depths, say 5 or 6 floors, stairs would be onerous and ramps more desirable even though more expensive, as noted under 5.2.4. However, with landings, the 12 to 36 feet depths required for these shelters are no hardship and in view of lower costs, stairs were selected for entrance use for this study.

5.3 STAIR ENTRANCE DESIGN AND COST

Various types and shapes of stair entries constructed of corrugated steel conduit, concrete pipe and cast-in-place reinforced concrete elements were considered and the more promising ones were developed and costed.

5.3.1 SPIRAL STAIRS

The spiral staircase was compared with straight stairs. Although they can be easily installed within an economical cylinder and have a lower unit cost than straight stairs, they have certain disadvantages. First, the varying-width stair tread is quite hazardous for rapid descent. Second, when descending 24-36 feet as is required for the 500-and 1,000-man shelters, an intermediate landing is necessary and the spiral stair does not readily accommodate this. Third, the capacity and descent rate is slower than that of straight stairs and this cannot be compensated for by widening the stairs because of the necessity for keeping one hand on a rail for safety. Multiple spirals become more expensive than straight stairs because they are not easily combined in one well but required individual wells.

5.3.2 STRAIGHT STAIRS

Standard sized entrance units were established for type comparisons and these are adaptable to each shelter size investigated in this study.

As previously noted in Section 2, the National Board of Fire Underwriters (23) exit unit concept was followed. The capacities of stairs of various exit unit widths were used to develop the curve shown on Figure 5.1 to establish the capacity in persons per minute per inch of stair width. From this curve a size called a single unit entrance of 2'-8" width and one called a double unit entrance of 4'-0" width were selected for this study.

The single unit entrance has a capacity of 50 persons per minute or 250 in the five minute entry time and a double unit has a capacity of 100 per minute or 500 in the five minute entry time. Some possible arrangements of entrance-exit packages are shown on Figures 5.2 through 5.6.

Circular, and oval cross-sections of corrugated steel or reinforced concrete were compared with rectangular reinforced concrete sections for the stair tunnel for both entrance unit widths as follows. These cross-sections are shown on Figures 5.7 and 5.8.

	Shape of Cross Section		
	Circular	Oval	Rectangular
Single Entr. Unit			
Corrug. Steel	$56.20	$58.80	
Reinf. Concrete	51.00	52.50	$27.00
Double Entr. Unit			
Corrug. Steel	$62.40	$63.00	
Reinf. Concrete	58.00	60.00	$31.00

Costs are per linear foot.

Following this cost comparison it was decided to use the reinforced concrete rectangular cross-section for the stair tunnels rather than one of the precast shapes.

The NBFU class "C" stair slope of 1:1 was selected as a satisfactory stair slope.

The headroom used in the entrance cross-section was 6'-6" when the passage is horizontal. This gives a minimum of 6'-4" from the nose of a stair tread to the closet obstruction overhead. This is considered adequate. Normal construction usually provides 6'-6". The NRDL (1) shelter entrance uses a headroom of 5'-6".

The depths from ground level to the point of entry for the three sizes of shelter were determined to be in the vicinity of 12 feet, 24 feet and 36 feet for the 100-person, 500-person and 1000-person shelters respectively. The cost incurred because

of the structural complications involved in entering the larger shelters at upper floors must be offset against the saving in excavation with a reduced entrance depth. After a preliminary comparison, it was concluded to be more economical to go to the main floor of the shelter in all cases.

Two general types of reinforced concrete entrances were investigated. These are:

1 - Stair Well type - Flights of stairs running from ground level parallel with the walls of a square or rectangular well. In the case of the square well, each given run on a side would consist of a landing, a set of stairs, then a landing for the 90-degree change in direction and so on. In the case of a rectangular well there would be flights of stairs running parallel with the long dimensions of the well with a reversal of direction at each end wall from landings. The rectangular stair well type is shown on Figure 5.9. This rectangular type has an advantage in that a single or double unit can be doubled in capacity, if required, by installing double run or scissor stairs (two runs of stairs start at the top, one at each end of the well and run down in opposite directions, crossing midway to landings where direction is reversed and the arrangement repeated) and providing two entrances (one for each set of stairs) to the shelter tunnel.

2 - Vestibule type - one straight flight of stairs from ground level to a vestibule and then down a straight flight of stairs to the shelter tunnel. This type is shown on Figure 5.10.

Both of these entrance types as shown are provided with a chain link fence around the portal to prevent accidents. Precast planks or grating to cover the opening are an alternate for areas where the fence is undesirable.

As indicated previously, the shelters in this study have been selected at 35 psi with alternate costs for 60 psi and nominal live-loading to show cost variations. The over-pressure designs therefore call for blast doors. These doors are considered

to be built up panels of structural steel plate and beams, placed in a vertical position. On the premise that all projections above the normal ground surface (such as bulkhead embankments etc.) should be avoided, these doors are located below ground. Two methods of doing this were investigated. One was to place the door at the bottom of the stairs as with the stair-well type entrance. (Figure 5.9) The other was to provide a vestibule to obtain headroom below-ground and then to provide the door at the end of the vestibule before descending the main stairs to the shelter as shown for the vestibule type entrance on Figure 5.10.

Figure 5.9 also shows the transition section that is provided for each of these entrance types of minimize "shine" from radioactive debris that may be deposited in, or at the portal of, the entrance and to maintain the minimum three feet of earth shielding for the shelter itself. This consists of a right angle bend section of level tunnel, each leg being 3 feet long, which leads from the bottom of the stairs into the shelter.

Steel grating with structural steel framing has been used for the stair-well type entrance and for the vestibule type with the exception of the stair tunnel portion. Here concrete stairs were used.

5.3.3 STRAIGHT STAIR COSTS - 35 psi

The costs of double-and single-entrance 100 and 50 persons per minute respectively for the three nominal shelter depths for both the stair well and vestibule types are depicted in the curves on Figure 5.11. The vestibule type results in the lower costs and these are the ones included in the total entrance package costs used in subsequent shelter comparisons.

5.3.4 VESTIBULE TYPE ENTRANCE COSTS - psi VARIABLE

Costs are also estimated for nominal or low and 60 psi entrances for the three nominal depths and these are shown with the costs of the 35 psi entrance in the following table.

Depth (feet)	12		24		36	
Unit	Single	Double	Single	Double	Single	Double
Nominal Live-Load	$1,606	$1,871	$2,695	$3,115	$4,564	$5,289
35 psi	1,959	2,282	3,083	3,560	5,001	5,781
60 psi	2,327	2,723	3,554	4,115	5,576	6,477

5.4 EXIT

The exit part of an entrance package has no stringent rate of movement of people. Its minimum dimensions are those required for one person to leave the shelter. Its prime requisites beyond this is that it must provide resistance to blast and shielding from radiation consistent with that of the particular class of shelter for which it is provided and must be of minimum cost.

On the basis of the costs per linear foot of steel and concrete cross-sections developed for stair tunnels, a reinforced concrete structure consisting of a vertical column section topped by a submarine-type blast-resistant hatch and with a manhole-type vertical ladder leading to a reinforced concrete horizontal section into the shelter has been selected.

Estimated costs for this exit complete for the three nominal depths and three pressures are shown in the following table.

Depth (feet)	12	24	36
Nominal Live-Load	$610	$778	$945
35 psi	750	955	1160
60 psi	914	1165	1417

(text continued on page 104.)

FIRE STAIR CAPACITIES [23]

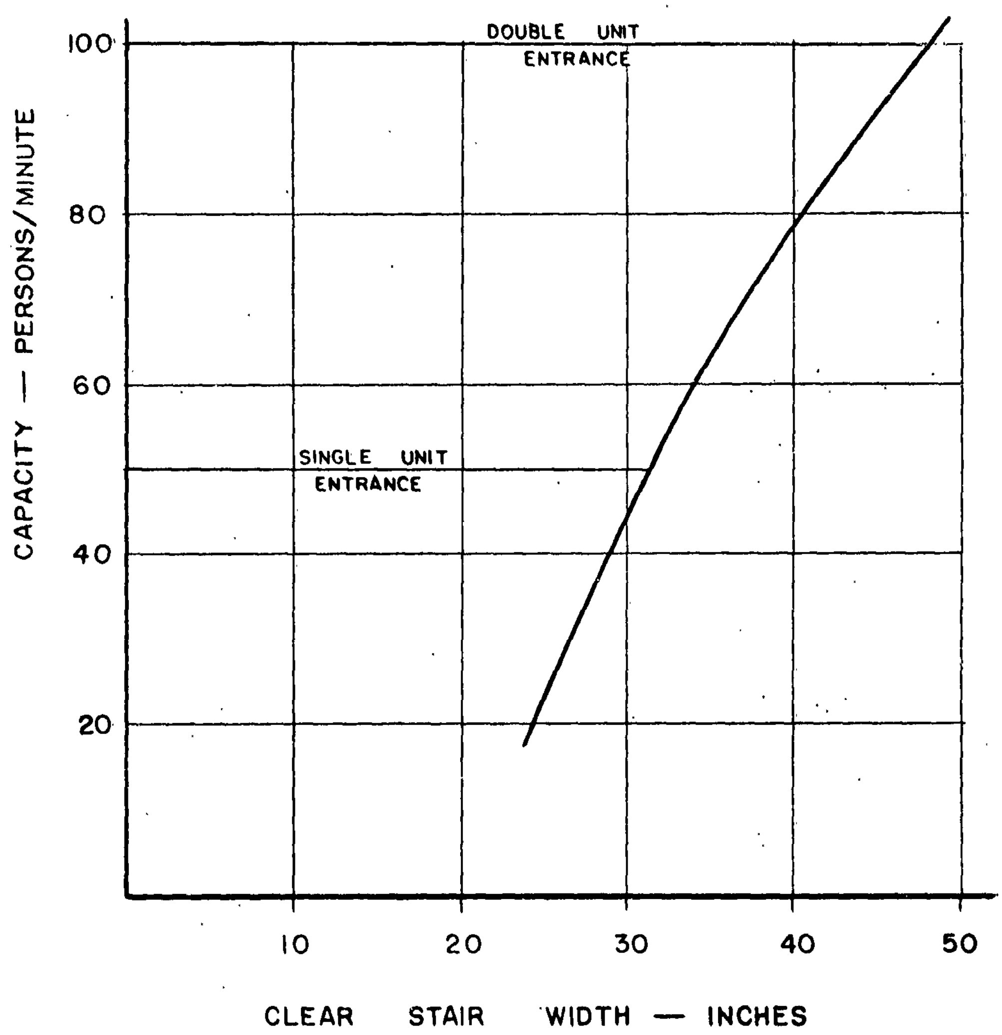


FIG. 5.1

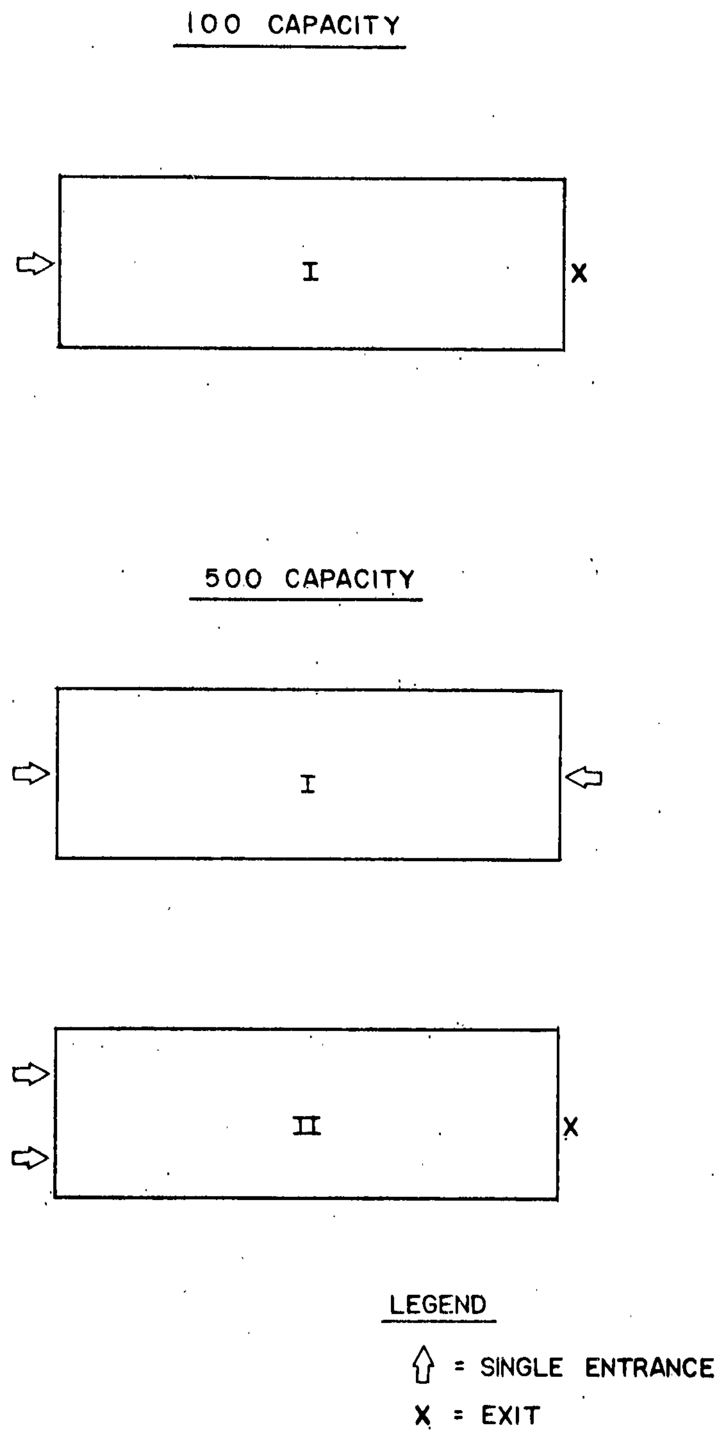

100 CAPACITY
I
X
500 CAPACITY
I
II
X
LEGEND
= SINGLE ENTRANCE
X = EXIT

FIG. 5.2

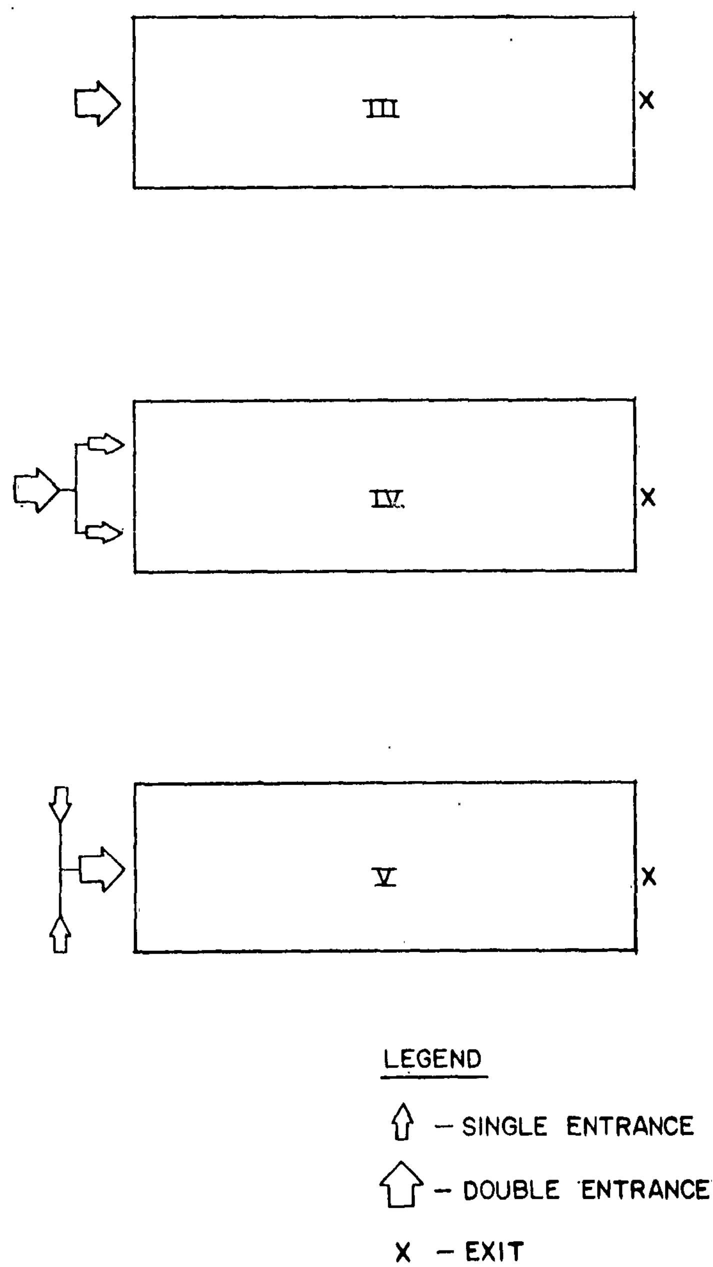


FIG. 5.3

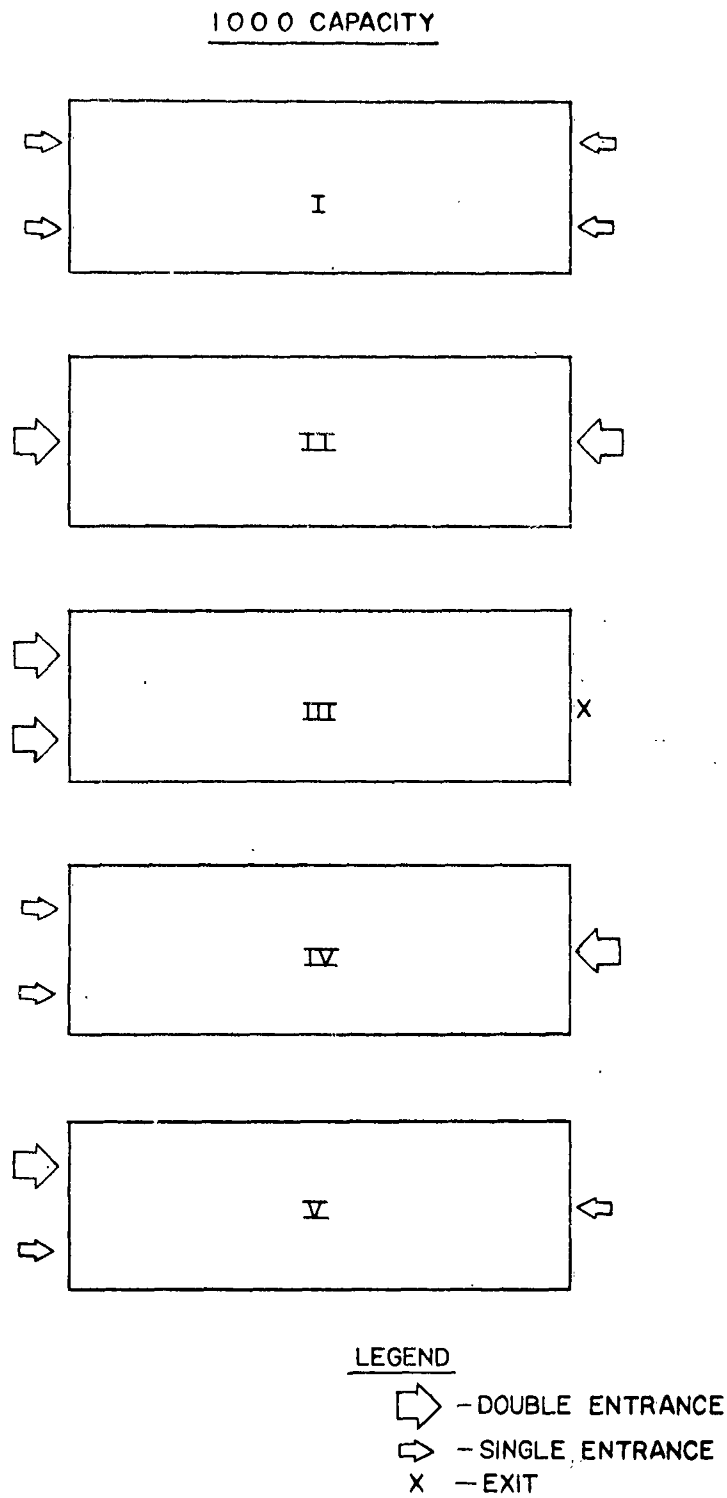
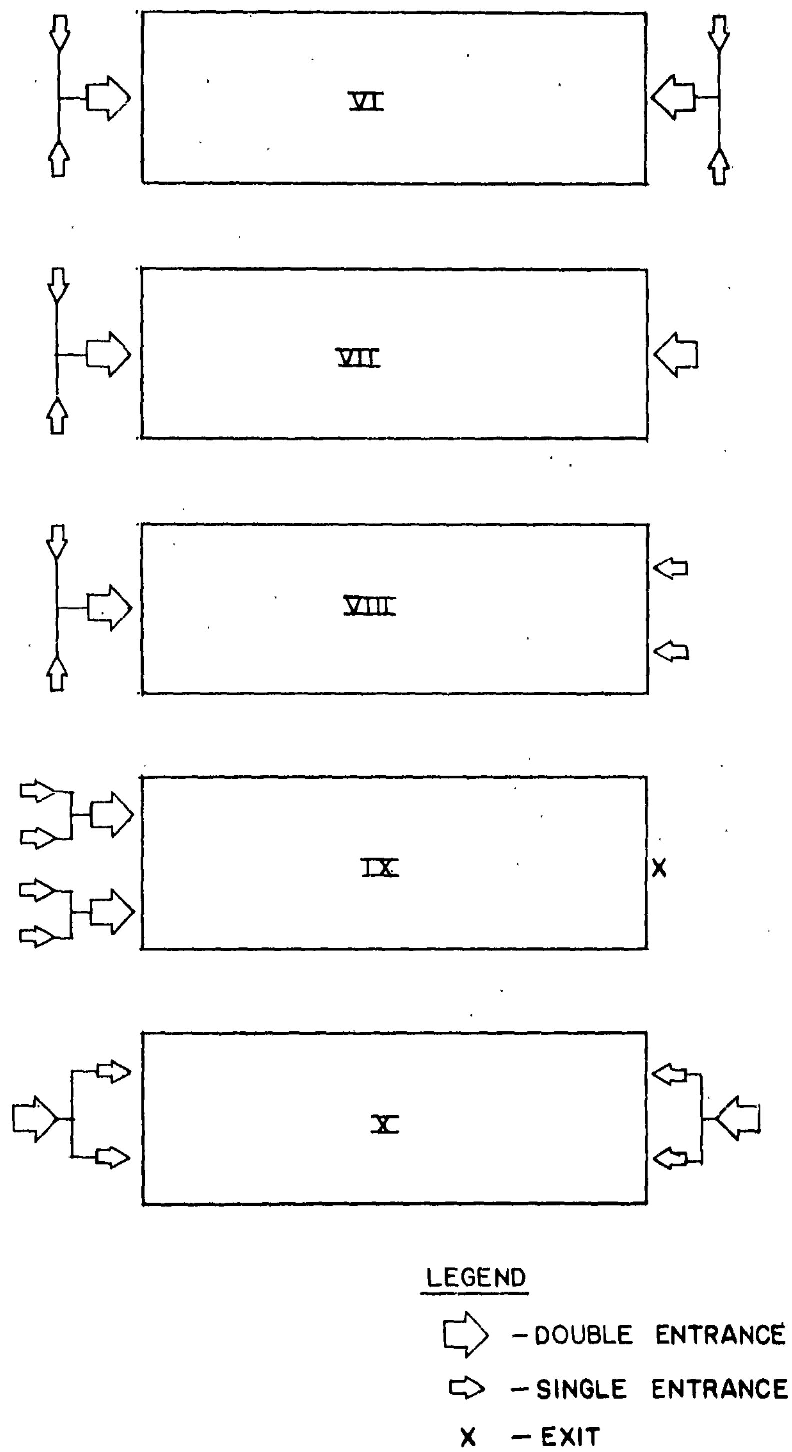

1000 CAPACITY
I
II
III
X
IV
V
LEGEND
- DOUBLE ENTRANCE
- SINGLE ENTRANCE
X — EXIT

FIG. 5.4



VI
VII
VIII
IX
X
X
LEGEND
- DOUBLE ENTRANCE
- SINGLE ENTRANCE
X - EXIT

FIG. 5.5

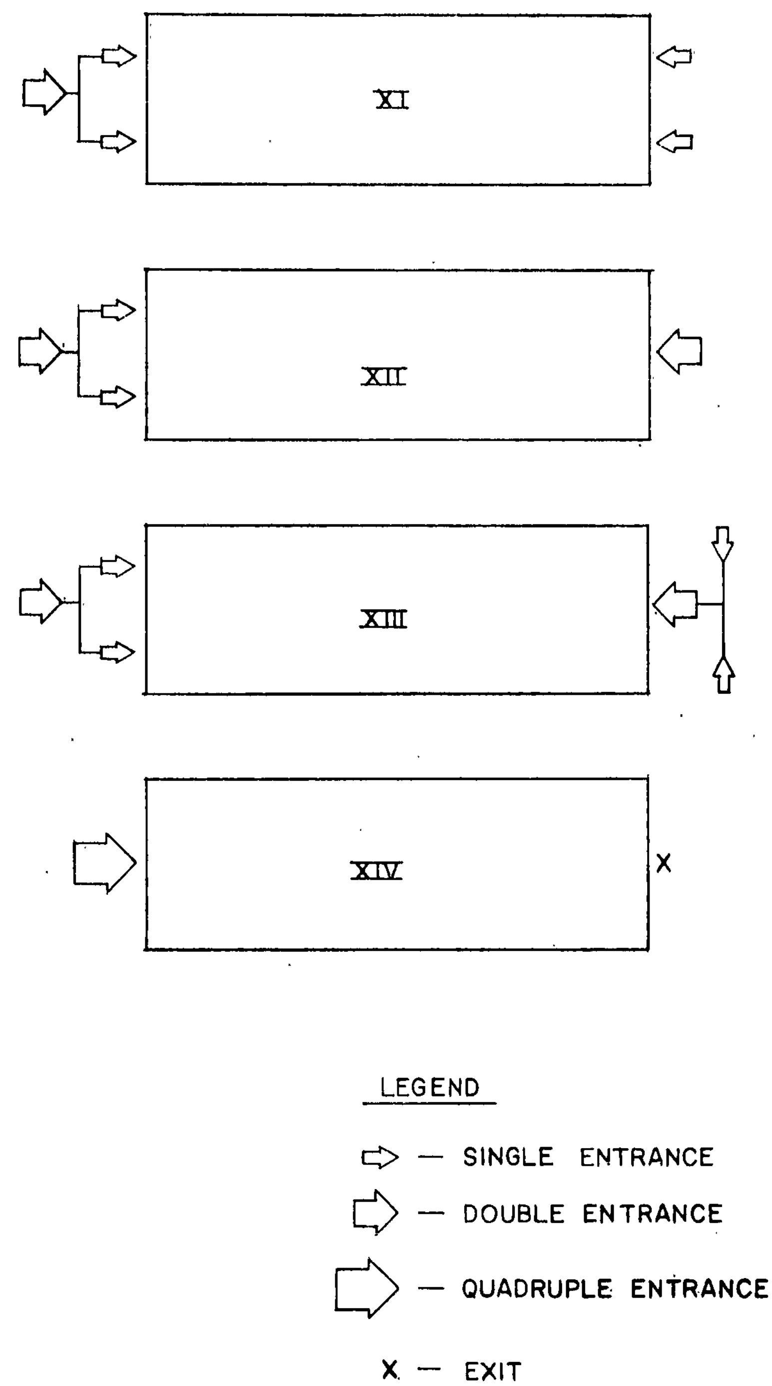
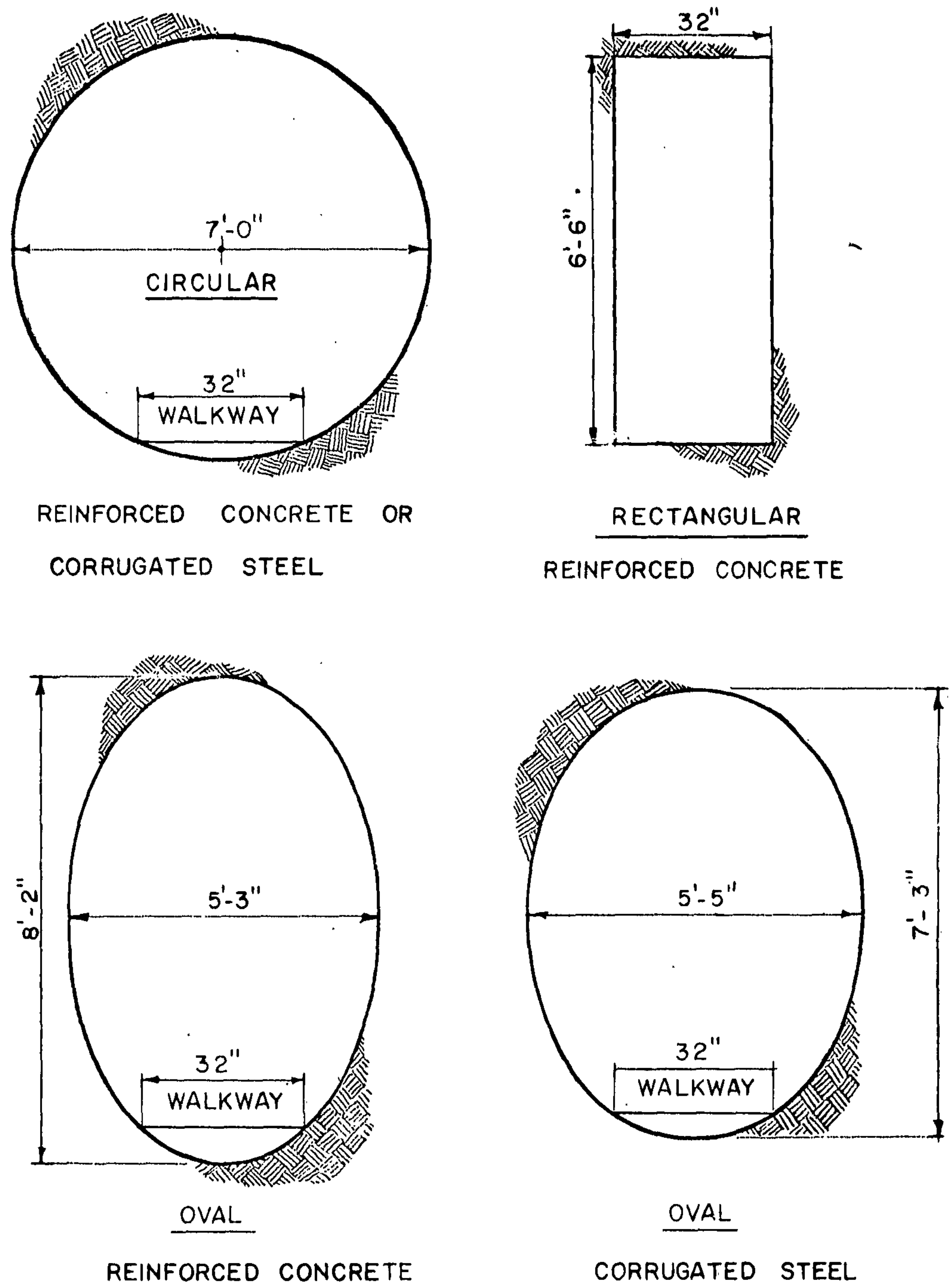

XI
XII
XIII
XIV
X
LEGEND
— SINGLE ENTRANCE
— DOUBLE ENTRANCE
— QUADRUPLE ENTRANCE
X — EXIT

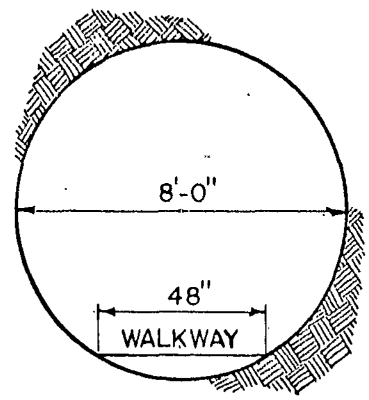
FIG. 5.6



POSSIBLE CROSS – SECTIONS FOR SINGLE UNIT (250 PERSONS)

ENTRANCE.

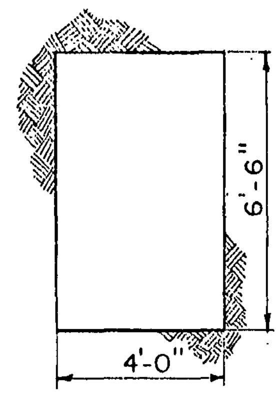
FIG. 5.7



CIRCULAR

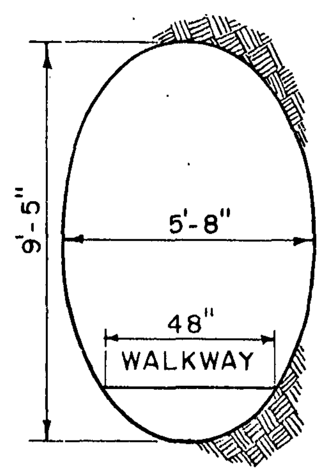
REINFORCED CONCRETE OR

CORRUGATED STEEL



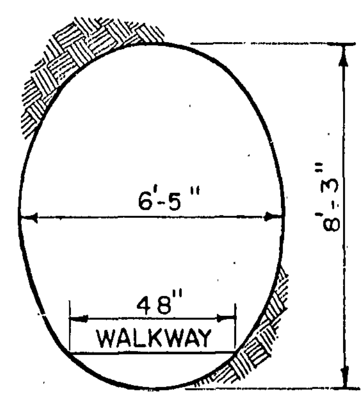
RECTANGULAR

REINFORCED CONCRETE



OVAL

REINFORCED CONCRETE



OVAL

CORRUGATED STEEL

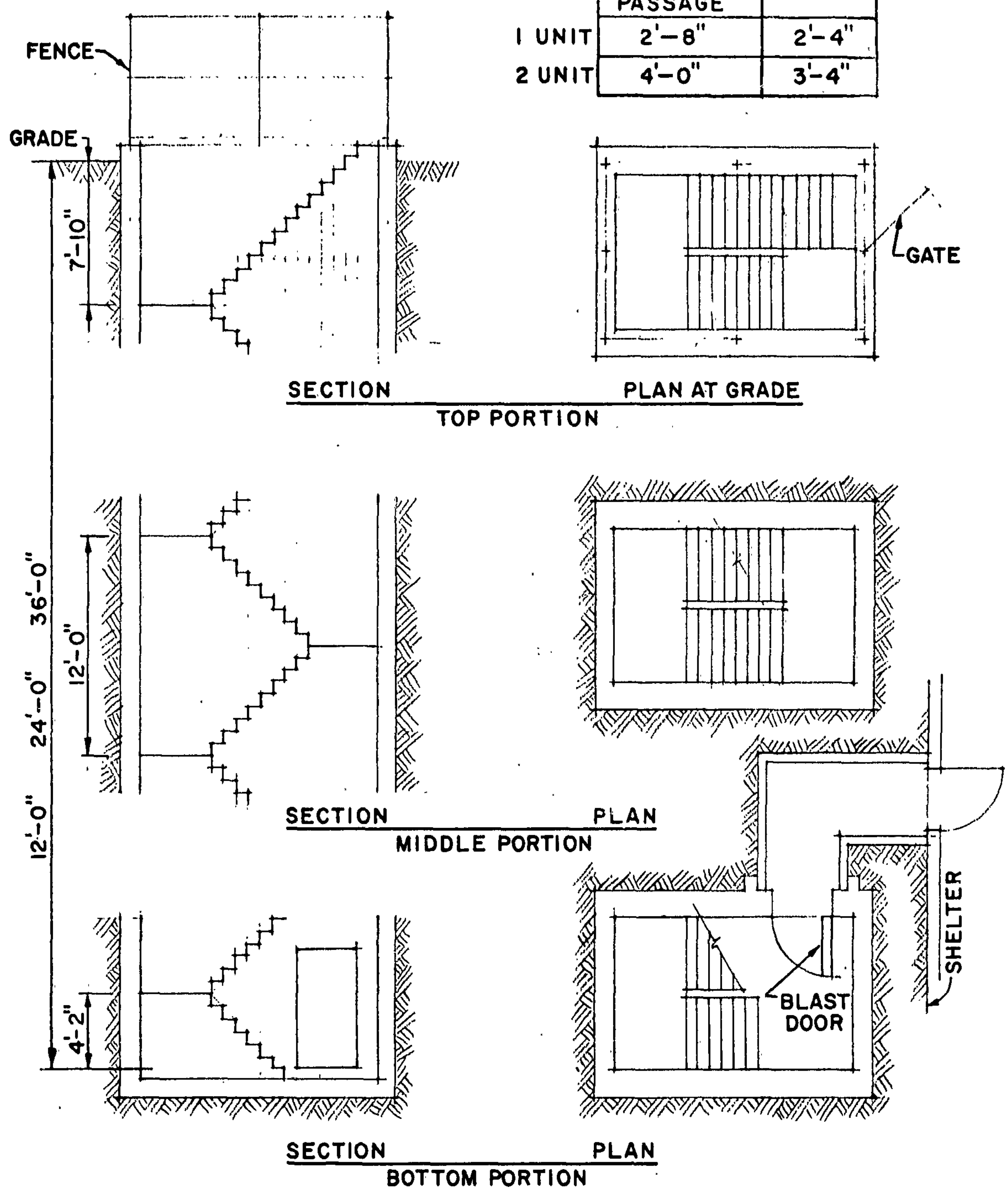
POSSIBLE CROSS—SECTIONS FOR DOUBLE UNIT (500 PERSONS)

ENTRANCE

FIG. 5.8

ALL STAIRS AND PLATFORMS
STEEL GRATING

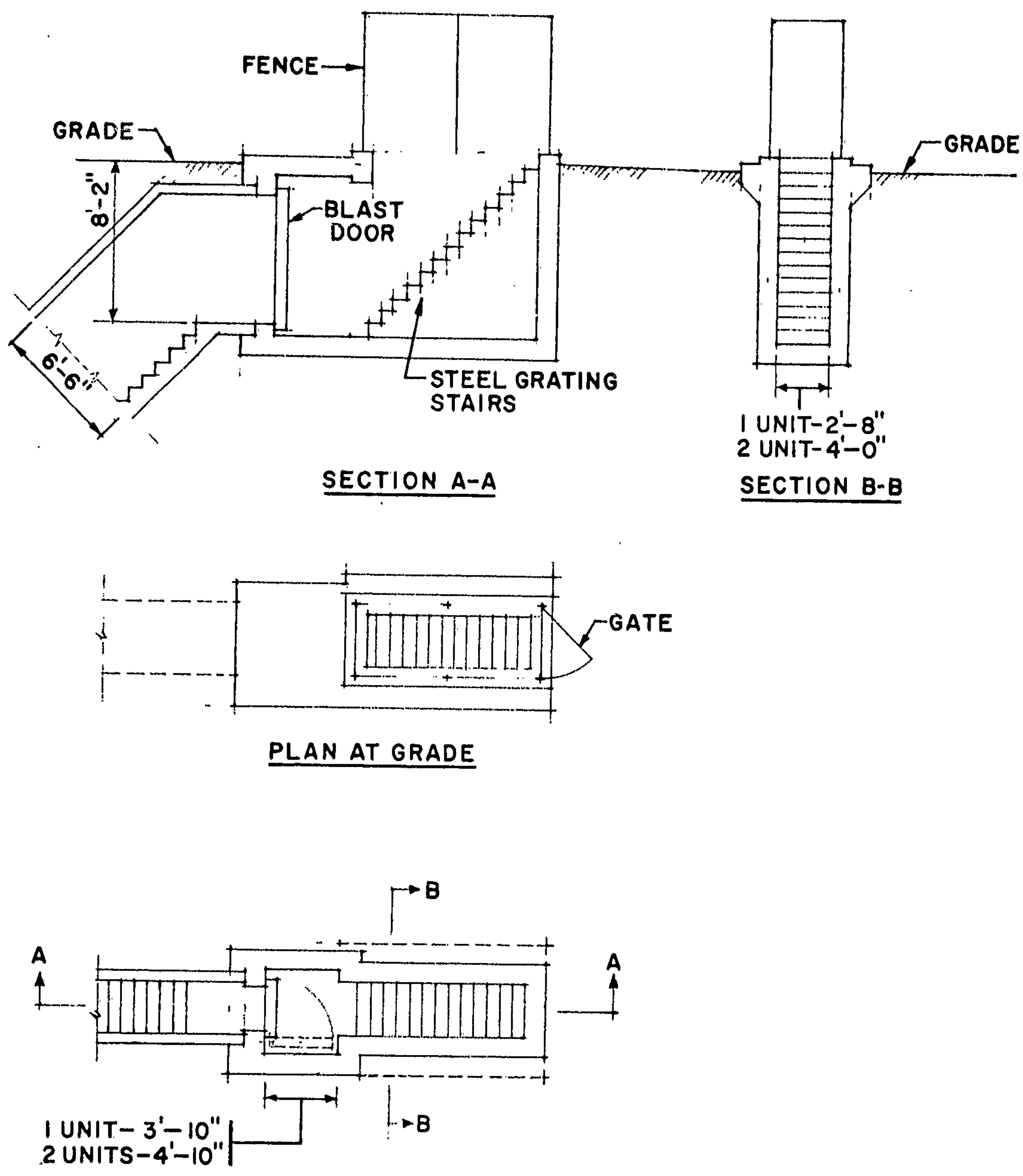
	WIDTH	
	STAIR AND PASSAGE	DOORS
1 UNIT	2'–8"	2'–4"
2 UNIT	4'–0"	3'–4"



ENTRANCE PACKAGE
(STAIR WELL TYPE)

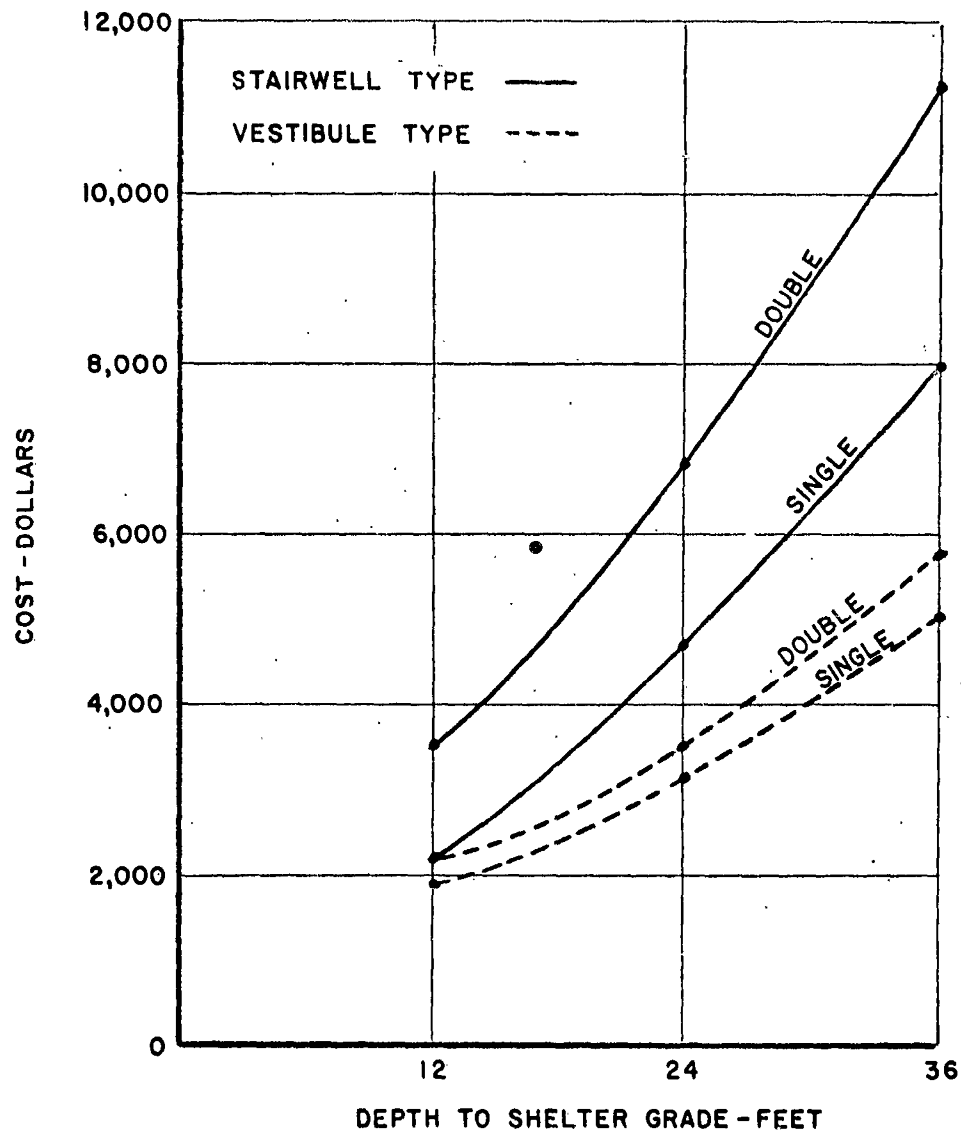
FIG. 5.9

SCALE: 1/16"=1'-0"



ENTRANCE PACKAGE
(VESTIBULE TYPE)

FIG. 5.10



ENTRANCE PACKAGE COSTS (35psi)

FIG. 5.11

SECTION 6

THE INFLUENCE OF UTILITIES

6.1 INTRODUCTION

In any study aimed at establishing optimum shelter configurations for planning purposes, it is necessary to consider effects of shelter requirements beyond structural and living space needs. We are, for example, aware of the several physiological needs of shelterees; such as: adequate atmospheric environment, food, water, waste disposal and lighting. We are also aware of the need of relating the performance of such items to overall survivability and of providing performance on a compatible basis. Presumably such an approach leads to minimum cost.

If this were a comprehensive shelter study, this approach might be taken, albeit applying survivability ratings to utilities and designing them at a compatible level may be difficult to do. That is, it is "easy" to prepare a structural design at, say, 35 psi with exits and openings compatible at this level; it is more difficult to select a compatible sanitary or food system because these are not obviously relatable to overpressure criteria. In short, shelters include many features with designs based on different kinds of criteria.

This may or may not be a serious problem in selecting shelter utilities especially for the purposes of this study. There are some reasons for increased confidence: First, we are better informed about utility performance through previous studies and simulated test programs. Secondly, we have learned to treat shelter utilities as such and not confuse them with utilities found in conventional structures. Thirdly, unlike the irrevokable nature of the shelter structure itself, it may be possible to upgrade or retrofit the utility system as the threat changes and as new designs become available.

With such confidence, it seemed possible to select utility systems in a reasonable manner, such that investigations into the interaction of utilities and shelter configurations would lead to some meaningful results. That is, results in terms of optimum configurations, not optimum utilities. Our emphasis, then, is in the

items which appear to have maximum cost versus performance effects.

Among such items are those which are required for or influence the maintenance of adequate environmental conditions within the shelter. The overall environmental problem is generally handled in two parts. The first involves the dissipation of internally generated heat to maintain survivable temperatures, and the second is concerned with providing a breathable atmosphere (i.e. the O_2 - CO_2 problem). Our treatment of shelter utilities is limited to applying general solutions to this (these) problem (s). There are, of course, requirements for other utility systems such as sewerage, food and water, lighting and communications. We have treated these lightly (or not at all) since their influence on shelter configuration appeared to be minimal.*

Among the specific tasks selected for study are the following:

1 - To determine the extent and value of heat dissipation through the shelter walls over a 14-day period.

2 - To identify those configurations which allow for the dissipation of all metabolic heat through the shelter walls during a 24-hour closure period.

3 - To develop space requirements for ventilation-heat dissipation packages and to determine their optimum location. (i.e. in the entrance package, separate and outside the shelter or within the shelter)

4 - To estimate the cost per capita differences of environmental control systems between large and small shelters.

5 - To rate the various configurations from the utility viewpoint.

* These items are specifically treated in concurrent studies e.g. 1309 - on sanitation systems, 1301-2 on food, 1305 - on water, 1311 - on lighting and 1505 - on communications.

The results of this analysis are dependent on the approach we have used. The criteria are general. The resulting optimum configuration based upon average utility design may not be optimum for a particular location. We have also limited the analysis to powered shelters because the CBR filtering requirement together with outside environmental design conditions appears to preclude the use of manually operated ventilating equipment. Beyond these caveats, we caution that the final cost figures developed are presented only for comparison purposes. They are not actual costs to be expected in providing environmental control systems.

6.2 14 - DAY HEAT TRANSFER

This part of the study effort involves the determination of performance differences between various shelter shapes and sizes in terms of heat transfer to soil over a 14-day period.

6.2.1 CONFIGURATIONS CONSIDERED FOR STUDY

Three basic configurations were considered; Rectangles, Arches, and Domes. Each type of configuration has three sizes or capacities: 100, 500, and 1000-person. A "minimum cross-section" configuration is also considered. The reason this was done was to show what is possible at the upper end of the heat transfer spectrum. This configuration, which we have termed "minimum," is minimum in the sense that it accommodates 2 side loaded bunks and common access aisle. This cross-section may be arranged in many plan configurations. We chose an "H" configuration to study the effects of heat transfer on adjacent structures. The various configurations are shown on Figures 6.1-6.10, and will be referred to in the following way:

IR	100-person	rectangle
IA	100-person	arch
ID	100-person	dome
IIR	500-person	rectangle
IIA	500-person	arch
IID	500-person	dome
IIIR	1000-person	rectangle
IIIA	1000-person	arch
IIID	1000-person	dome
Minimum cross-section		100-person "H"

The three arches are approximately equal in length and density in terms of area per person. Configurations IA and ID have one floor; IIA and IID, two floors and IIIA and IIID, three floors. The rectangular structures are single floor with headroom selected to accommodate 4-high bunking.

6.2.2 ASSUMPTIONS

Among the several assumptions made, are the following:

1 - Table 6.1 lists the characteristics of four different soils, ranging from good to poor. In this study a normal compact silt and clay soil is termed a "poor" soil and a wet compact sandy soil is referred to as a "good" soil. These two extremes represent a range of possible soils that might be found in the United States. (32)

2 - Three soil temperatures were used in the study: 55°F, 65°F and an "actual" soil temperature. 55°F is approximately the nation-wide average non-thermal well-water temperature. (33) 65°F was selected to show the effect of higher temperature. The "actual" soil temperature is the highest average temperature of Washington D.C. at various depths. It is used in the numerical approach to the problem. (See Figure 6.11)

3 - To show the effect of concrete, we will assume an average thickness of 1' and a thermal conductivity of 12 BTU/Hr./Ft./F. (21)

4 - Each configuration has at least 3' of earth cover.

5 - Initial shelter temperature equals soil temperature.

6 - Metabolic rate of the shelterees is 500 BTU/Hr./person, consisting of latent and sensible heat whose relationship is given in Section 2.2.3 and shown on Figure 6.12.

7 - All surfaces transfer heat at the same rate and the flow of heat is normal to the walls. Edge and end effects are neglected.

TABLE - 6.1

Various Soils Considered in Heat Transfer Problem

TYPES	THERMAL (K) CONDUCTIVITY BTU/HR-FT-°F	SPECIFIC HEAT (C) BTU/LB -°F	DENSITY (ρ) LB/FT^3	THERMAL DIFFUSIVITY ($\alpha = \frac{K}{\rho C}$) FT^2/HR
Silt & Clay				
1. Normal Compact	0.782	0.233	120	0.028
2. Wet Compact	0.982	0.257	120	0.031
Sandy Soils				
3. Normal Compact	1.66	0.206	140	0.0575
4. Wet Compact	1.91	0.218	140	0.0626

Soil #1 shall be referred to as a "Poor Soil", P.S."

Soil #4 shall be referred to as a "Good Soil, G.S."

These two soils will be compared throughout this section on Heat Transfer.

Some factors which influence heat transfer that were not considered are:

1 - The existance of entries and exits.

2 - Humidity.

3 - Weather conditions.

4 - Unusual soil conditions.

5 - Ground surface conditions.

6.2.3 METHOD OF APPROACH

Two methods were used to evaluate the 14-day heat transfer problem. The first method follows the technique recommended by the Corps of Engineers. (33) Two results may be obtained by using this method:

1 - The average heat transferred over 14 days to soils at different temperatures (BTU/Hr.-Ft^2)

2 - The density (Ft^2 floor space/person) that each configuration can accommodate to keep the final temperature inside the configuration at some assigned value.

The second method uses a numerical approach to the problem. The reasons for using this method are as follows:

1 - As a check on the Corps method.

2 - To develop a time-temperature soil history.

3 - To determine a distance-temperature soil relationship.

The numerical approach permits these conditions to be investigated. Using the numerical method one may also obtain a value for the average heat transferred over 14 days. (BTU/Hr-Ft^2)

6.2.4 PARAMETERS

K	Thermal Conductivity	BTU/Hr-Ft-°F
c	Specific Heat	BTU/Lb-°F
ρ	Density	Lb/Ft^3
A	Total Surface Area of Configuration	Ft^2
m	Length of Configuration	Ft
n	Width of Configuration	Ft
$a_1 = A/2\pi m$	Equivalent Radius of Cylinder	Ft
$a_2 = (A/4\pi)^{1/2}$	Equivalent Radius of Sphere	Ft

For the warmup period:

θ_1	Temperature difference between initial soil temperature and temperature to be maintained in the configuration.	°F
t	Time	Hrs.

$F_{(1 \text{ or } 2)} = Kt/\rho c a^2_{(1 \text{ or } 2)}$, where F1 cylinder, F_2 sphere.
$f(F_1)$ and $f(F_2)$ found on Figs. 6.13 and 6.14.

U'	Coefficient of heat transfer between the configuration and the soil.	$BTU/Hr\text{-}°F\text{-}Ft^2$
$q' = K\theta_1/af(F) + \frac{K}{U'}$	Steady Heat Input to Configuration	$BTU/Hr\text{-}Ft^2$

For the Average Heat Transfer Rate:

$N = aU'/K$ Values for $f(F,N)$ found on Figs. 6.15 and 6.16.

R	Factory involving the ratio of the volume of heated soil around the cylinder or sphere to that around the actual configuration. (Figs. 6.17 and 6.18)	
$q=f(F,N)\Theta_1 U'/R$	Soil Heat Absorption Rate	BTU/Hr-Ft^2

6.2.5 OVERALL TRANSFER COEFFICIENT

U' is an extremely important constant in the evaluation of heat transfer. There are several factors that affect U'. These will be investigated in this section.

U' is determined as follows:

$$1/U' = 1/f_1 + x_1/K_1 + x_2/K_2 \;\ldots\ldots\ldots\ldots + x_i/K_i$$

U' is the total coefficient of heat transfer through all materials

f_1 is the film coefficient between air and the shelter wall (concrete)

x_1 is the thickness of material with thermal conductivity K_1

x_2, x_3 .... x_i refer to thickness of different materials of a composite wall, each having thermal coefficients K_2, K_3 .... K_i.

The coefficient, U', is applicable when heat is transferred from one medium to another through a barrier. In our case the media are air inside the configurations and the soil surrounding them. In our case, the equation for U' becomes

$$1/U' = 1/f_1 + 1/K_c + 1/K_s$$

K_c = Thermal Conductivity of concrete

K_s = Thermal Conductivity of soil

The thickness of the soil and concrete is assumed to be 1'.

K for the "good" soil is 1.91 BTU/Hr-Ft-°F

K for the "poor" soil is 0.782 BTU/Hr-Ft-°F

The film coefficient, f_1, and therefore overall coefficient, is somewhat dependent on air velocity. This relationship is shown on Figures 6.19 and 6.20. Within the range of air velocities expected, we would expect very little effect.

6.2.6 WARM-UP PERIOD

q' is the steady heat input required to raise the air temperature to a desired level in a given time. In our mathematical model this temperature never exceeds 100 °F in two weeks. (336 Hrs.) Surface area and equivalent radii and the corresponding R values were found for the various configurations. $q'f(\theta_1)$ was then computed. Knowing the total and the heat liberated, it is then possible to compute the floor area per person for various temperatures. The results are shown on Figures 6.21 - 6.40 in Appendix C-1. A summary comparison is shown on Figure 6.41.

6.2.7 AVERAGE TRANSFER RATE

The average transfer rates over a two-week period for the various configurations were computed. Individual results are shown on Figures 6.42 - 6.51. (Appendix C-2) and a summary shown on Figure 6.52.

6.2.8 A NUMERICAL APPROACH

The problem of calculating heat transfer over a 14-day period has the following conditions regardless of configuration:

1 - The configuration is at least 3' below ground and its geometry is known.

2 - At time T=0 people enter and remain for 336 hours.

3 - The initial soil temperatures are as shown on Figures 6.1 - 6.10.

4 - The boundary between the configuration and soil is known.

In order to find the time-temperature history (i.e. the temperature at any distance from the shelter at any time) it is necessary to obtain an additional boundary condition which is the distance from the shelter where soil temperature does not change. A scheme developed by Schneider, using Gauss' Integral (34) shows that at a distance of 18 ft. there is less than 1°F change of temperature at the end of 2 weeks. For the purposes of this analysis, this distance is sufficiently accurate for use as a boundary condition.

The method of solution involves dividing the configurations into specific soil mass-temperature segments and applying finite differences. (35) Figure 6.53 shows the nomenclature and the grid system used in the solution. The actual numerical solutions are not presented in this report. Using information from these solutions the quantity of heat transferred was computed as follows:

$$\Delta Q = KA\,\Delta T\,\Delta t/\Delta x, \text{ where}$$

ΔQ = quantity of heat transferred in time Δt over a distance from the configuration Δx

ΔT = Change in temperature over any increment, Δx

Δt = Time increment

This equation is usable in a continuous medium such as soil. At the interface of wall and soil the equation takes the form:

$Q = AU'\Delta T\Delta t$, where U' is the overall transfer coefficient.

Applying these equations to the various schemes gives the heat absorbed at various soil temperatures and depths and a value for the final air temperature inside the shelters. (Table 6.2).

The results for all configurations are shown on Figures 6.54 - 6.63 (Appendix C-3). A summary is given on Figure 6.64.

6.2.9 CONCLUSIONS

Within the limitations specifically imposed by the nature

TABLE - 6.2

Heat Absorbed Per Square Foot of Wall Surface

After 14 Days

(BTU)

SOIL CONDITIONS Temp.-F	Depth-Ft.	95F INSIDE G.S.*	P.S.*	85F INSIDE G.S.	P.S.	75F INSIDE G.S.	P.S.
55	3	519	62				
65	3	387	46				
Actual	3	440	52	310	261	180	93
65	8	1356	1060	900	709	451	355
55	10	2170	1397				
55	18	2562	1520	1943	1157	1201	770
60	18	2262	1300	1615	964	954	592
65	18	1934	1152				
Actual	18	2621	1436				

* G.S. = Good Soil; P.S. = Poor Soil

of this study, the following general statements can be made.

1 - Heat transfer calculations using the Corps of Engineers method will give results up to 2 times greater than those obtained from a numerical solution, depending on the configuration and soil conditions. This difference is greatest for the smaller configurations and least for the larger ones.

2 - Using conservative heat transfer rates, an order-of-magnitude comparison of the beneficial effects among the various configurations selected for study is as follows:

RATING	CONFIGURATION	AVERAGE HEAT TRANSFER BTU/HR/PERSON +	PERCENT OF TOTAL HEAT *
* 1	Min. Cross-Section	150	30
1	100-Man Arch	150	30
3	100-Man Dome	125	25
4	100-Man Rectangle	100	20
5	500-Man Arch	80	16
5	500-Man Dome	80	16
7	500-Man Rectangle	75	15
8	1,000-Man Rectangle	70	14
9	1,000-Man Dome	60	12
10	1,000-Man Arch	55	11

3 - Wet, sandy, compact soils will allow heat transfer rates of up to 2 times greater than dry, silt and clay, normally compacted soils.

4 - Under the best soil conditions, soil temperatures would not be expected to rise at a distance greater

\+ Average between results for good and poor soil conditions.

* Taken at 500 BTU/Hr/Person. Although the shelter walls will reject sensible heat only, it may be possible to fully utilize the heat dissipation capability through the use of devices which will convert latent to sensible heat or by condensation on the shelter walls.

than 20' from the shelter wall. Approximately 85% of total heat transfer would occur within a distance of 10' of the shelter wall.

5 - For single-story rectangular configurations an increase in soil cover from 3 feet to 18 feet will result in as much as a 45% increase in heat transfer. For other configurations this effect is less.

6 - Over a fixed time period, a decrease in metabolic heat rate will result in a proportionate increase in the fraction of heat transferred through the shelter walls.

7 - An increase in average soil temperature from 55F to 65F will result in a heat transfer decrease of 30 to 45%.

6.3 MECHANICAL-ELECTRICAL PACKAGES

The purpose of this phase of the study is to determine the effects of environmental control systems on shelter configuration. Although it was necessary to do some extensive design computations in order to select equipment, this is not a comprehensive system study.

6.3.1 ENVIRONMENTAL CONTROL METHODS

Beyond providing minimum outside air for ventilation, there is a requirement to dissipate internally generated heat. Some of the ways this might be done are:

1 - Straight outside air--sufficient outside air is supplied to the shelter to maintain the desired effective temperature.

2 - Well-water cooling--return air from the shelter is cooled and dehumidified by water coils, then mixed with a minimum of outside air, and the mixture then supplied to the shelter.

3 - Refrigerant cooling--as in (2) above, except return air is cooled and dehumidified by direct expansion

(DX) coils. Condenser might be air-cooled or water-cooled.

4 - Chemical dehumidification--This method converts latent heat to sensible heat. It is not exactly a heat dissipation scheme.

5 - Underground pipes and heat sinks.

In the following study, we will investigate methods 1, 2 and 3.

6.3.2 PSYCHROMETRICS OF THE SELECTED METHODS

Psychrometrics for each of the above methods were calculated on the basis of no heat transfer through the shelter walls and on the basis of using maximum heat transfer as obtained from results of the previous section. Presumably this will cover the range of effects of heat transfer on the cost and performance of the environmental control systems. Using the basic criteria as described in Section 2.2.3, estimated heat outputs which must be dissipated by any system over a variety of temperatures are shown in Table 6.3. Using these figures, we have graphically described the psychrometrics on Figures 6.65 through 6.68. From these we have calculated quantities based on the following:

Case I - Ventilation only, no heat transfer--30 cubic feet of outside air per minute per person required to maintain 85°F E.T.

Case II -Well-water cooling, no heat transfer--with 15 cfm supply including 3 cfm of outside air and assuming a 15°F water temperature rise, the system requires 4.8 gallons of water per hour per person.

Case III - Refrigerant cooling, no heat transfer--with air quantities as in Case II, 0.045 tons of refrigeration are required per person.

Case IV -Ventilation only, including maximum heat transfer--15 cfm per person of outside air will maintain 85°F E.T.

TABLE 6.3

HEAT PRODUCTION QUANTITIES

SHELTER D.B. TEMP. (F)	MAX. W.B. TEMP. + (F)	LATENT HEAT OUTPUT PER OCCUPANT QL (BTU/HR)	EST. SENSIBLE HEAT OUTPUT PER OCCUPANT INCL. LIGHTS AND EQUIP. QS (BTU/HR)	SENSIBLE HEAT FACTOR ($\frac{QS}{QT}$)	AVG. HEAT TRANSFER THROUGH WALLS PER OCCUPANTS * (BTU/HR)	SENSIBLE HEAT FACTOR ($\frac{QS}{QT}$)
85	85	295	275	.48	134	.33
86	84.5	308	262	.46	139	.29
87	84	322	248	.44	144	.24
88	83	336	234	.41	149	.20
89	83.5	350	220	.39	154	.16
90	82	363	207	.36	159	.12
91	81.5	377	193	.34	164	.07
92	80.5	391	179	.31	169	.03
93	80	405	165	.29	174	--
94	79.5	418	152	.27	179	--
95	79	432	138	.24	184	--

$QS + QL = QT$

* Average heat transfer through walls per occupant means the average sensible heat transferred in BTU/Hr/Occupant from the shelter to the surrounding medium over a period of 14 days. These values are for the shelter configuration in which the maximum heat transfer rate occurs.

+ To maintain 85°F effective temperature.

Case V - Well-water cooling, including maximum heat transfer--with air quantities as in Case II, Water requirements are 3.6 gallons per hour per person.

Case VI -Refrigerant cooling, including maximum heat transfer--with air quantities as in Case II, 0.025 tons of refrigeration are required per person.

With this information, it is possible to size and assemble the various equipment required into individual packages and determine their costs and cost differences.

6.3.3 SELECTION OF EQUIPMENT PACKAGES

Mechanical-electrical equipment packages were divided into units of 100, 250 and 500. In general, this was done to coincide with the capacity of the entrance units since it seemed preferable to use entrances as intake air plenums and because there was a possibility that the optimum location for the equipment would be within the entrance passageway. Smaller packages also allow for easier movement and installation and will provide for greater flexibility and, perhaps, reliability.

General information concerning the selection of equipment for the various packages is as follows:

1 - Fan--Conventional centrifugal fan with direct drive, constant speed (2-speed for the ventilation only case) motor with inlet vane control. Horsepower requirements are based on a 63% fan-motor efficiency at a static pressure of 5 inches of water.

2 - Filters--U.S. Army Chemical Corps type CBR filters including prefilters.

3 - Electric generating plant--Standard gasoline powered packaged units, air-cooled with sizes up to 15 KW and water-cooled with radiators above 15 KW. All generators are battery started; sizes below 15 KW can also be manually started. System includes a fuel tank with sufficient capacity for 14 days.

This tank is assumed to be buried alongside the shelter. A typical electrical system is shown on Figure 6.69.

4 - Well-water cooling equipment--Vertical, submerged turbine-type pump with direct-drive motor mounted in a 4" casing. Well depth is taken at 200 feet. Pump supplies water to standard cooling coils mounted in a return air duct.

5 - Refrigerant cooling equipment--Refrigerant compressor, direct expansion coil and air-cooled condenser. Arrangement includes base-mounted reciprocating compressor (using refrigerant R 12 or R 22), with a direct-drive suction-gas-cooled electric motor and a receiver. Direct expansion coils are located in a return air duct. A remote mounted condenser is cooled by unfiltered air supplied by a direct-drive axial fan.

Other equipment such as ductwork, dampers and controls, intake and exhaust connections, blast closures, piping, supports and partitions have been included as required. Exhaust air at 3 cfm per person is assumed to exit past the toilet area.

6.3.4 EQUIPMENT ARRANGEMENTS

In arranging the various equipment into packages, we had two objectives in mind. First, to determine space requirements and secondly, to determine optimum location (i.e. inside or outside the shelter). To reduce the number of possible combinations, space requirements have been allocated such that any of the three basic systems could be accommodated. Composite layouts were completed for the three package sizes, located as follows:

In a circular entrance section	(Fig. 6.70)
In a rectangular entrance section	(Fig. 6.71)
Inside the shelter	(Fig. 6.72)

In preparing these layouts, the CBR filters were always shielded and/or located to prevent radiation streaming.

Having established approximate areas and section lengths,

it is now possible to cost-compare the arrangements and determine an optimum. The following analysis includes only those items directly chargeable to the packages. The cost of interior shelter area used is roughly typical of the optimum configurations.

Circular Pipe (Corrugated Steel) Section Entrance

100-man unit	-	25' of 8' dia. pipe @ $ 62	=	$1550
250-man unit	-	27' of 9' dia. pipe @ $76	=	2050
500-man unit	-	35' of12' dia. pipe @ $140	=	4900

Rectangular Section Entrance

100-man unit	-	25' of 8' x 6'-6" conc. sect. @ $37	=	$ 925
250-man unit	-	27' of 9' x 6'-6" conc. sect. @ $40	=	1080
500-man unit	-	35' of 12' x 6'-6" conc. sect. @ $65	=	2275

Interior package

		Inside Cost	+ Outside Cost	+ Entrance Section		
100-man unit	-	49 sq.ft. @ $8	+ $265	+ 8.5' @ $22	=	$ 845
250-man unit	-	64 sq.ft. @ $7	+ $355	+ 9' @ $22	=	1000
500-man unit	-	81 sq.ft. @ $6.50	+ $665	+ 12' @ $28	=	1528

Within the limitations of this analysis, we may conclude that mechanical-electrical packages are optimumly located inside the shelter proper.

6.3.5 PACKAGE COSTS

Cost estimates for the various packages are given in Tables 6.4 through 6.10. These costs are presented for comparison purposes only. Overhead, contingencies and contractors' profits are not included.

6.3.6 CONCLUSIONS

Within the limits of this investigation, the following statements can be made:

1 - Designs based on cooling with outside air only tend to be most expensive if there is a requirement for

(text continued on page 129)

TABLE 6.4

Package Costs

(Without Heat Transfer)

100-Person Unit

CASE I	VENT ONLY
CASE II	WELL-WATER COOLING
CASE III	REFRIG. COOLING

		CASE I	CASE II	CASE III
(A)	Vent Fan - 3000 CFM	400	---	---
(B)	Vent & Recirc. Fan - 1500 CFM	---	320	320
(C)	C.B.R. & Prefilter - 3000 CFM	4,280	---	---
(D)	C.B.R. & Prefilter - 300 CFM	---	400	---
(E)	Well-water Pump - 8 g.p.m.	---	2,260	---
(F)	Well-water Coil - 18" x 24" x 6 rows	---	310	---
(G)	Refrig. Comp. & A/C Cond. - 4.5 Tons	---	---	1,970
(H)	D.X. Coil - 18" x 24" x 4 rows	---	---	170
(I)	Engine Generator Set - 7.5 KW	---	2,200	---
(J)	Engine Generator Set - 15 KW	3,500	---	3,500
(K)	Fuel Tank - 14 Day	400	300	400
(L)	Lights, conduit and motor controls	890	860	970
(M)	Ducts, Piping, Supports and Partitions	730	650	770
	TOTAL	$10,200	$ 7,300	$ 8,500
	Cost per person	$ 102	$ 73	$ 85
	Blast Closures 35 or 60 psi	8	2	6
	Cost per person	$ 110	$ 75	$ 91

TABLE 6.5

Package Costs

(Without Heat Transfer)

250-Person Unit

CASE I VENT ONLY

CASE II WELL-WATER COOLING

CASE III REFRIG. COOLING

		CASE I	CASE II	CASE III
(A)	Vent Fan - 7500 CFM	770	---	---
(B)	Vent & Recirc. Fan - 3750 CFM	---	480	480
(C)	C.B.R. & Prefilter - 7500 CFM	6,560	---	---
(D)	C.B.R. & Prefilter - 750 CFM	---	1,300	1,300
(E)	Well-Water Pump - 20 g.p.m.	---	2,460	---
(F)	Well-Water Coil - 24" x 30" x 6 rows	---	440	---
(G)	Refrig. Comp. & A/C Cond. - 10 Tons	---	---	3,370
(H)	D.X. Coil - 24" x 30" x 4 rows	---	---	290
(I)	Engine Generator Set - 15 KW	---	3,500	---
(J)	Engine Generator Set - 25 KW	3,900	---	3,900
(K)	Fuel Tank - 14 Day	450	400	450
(L)	Lights, conduit and motor controls	1,570	1,310	1,610
(M)	Ducts, Piping, Supports and Partitions	1,250	1,245	1,100
	TOTAL	$14,500	$11,000	$12,500
	Cost per person	$ 58	$ 44	$ 50
	Blast Closures 35 or 60 psi	8	2	6
	Cost per person	$ 66	$ 46	$ 56

TABLE 6.6

Package Costs

(Without Heat Transfer)

500-Person Unit

CASE I — VENT ONLY

CASE II — WELL-WATER COOLING

CASE III — REFRIG. COOLING

		CASE I	CASE II	CASE III
(A)	Vent Fan - 15000 CFM	1,250	---	---
(B)	Vent & Recirc. Fan - 7500 CFM	---	770	770
(C)	C.B.R. & Prefilter - 15000 CFM	13,000	---	---
(D)	C.B.R. & Prefilter - 1500 CFM	---	2,640	2,640
(E)	Well-Water Pump - 40 g.p.m.	---	2,740	---
(F)	Well-Water Coil - 30" x 42" x 6 rows	---	700	---
(G)	Refrig. Comp. & A/C Cond. - 2 x 10 Tons	---	---	6,490
(H)	D.X. Coil - 30" x 42" x 6 rows	---	---	520
(I)	Engine Generator Set - 25 K.W.	---	3,900	---
(J)	Engine Generator Set - 40 K.W.	4,800	---	4,800
(K)	Fuel Tank - 14 Day	600	500	600
(L)	Lights, conduit and motor controls	2,400	1,950	2,400
(M)	Ducts, Piping, Supports and Partitions	1,950	1,800	1,720
	TOTAL	$24,000	$15,000	$20,000
	Cost per person	$ 48	$ 30	$ 40
	Blast Closures 35 or 60 psi	8	2	6
	Cost per person	$ 56	$ 32	$ 46

TABLE 6.7

Package Costs

(Including Heat Transfer)

100-Person Unit

CASE IV VENT ONLY

CASE V WELL-WATER COOLING

CASE VI REFRIG. COOLING

		CASE IV	CASE V	CASE VI
(A)	Vent Fan - 1500 CFM	320	---	---
(B)	Vent & Recirc. Fan - 1500 CFM	---	320	320
(C)	C.B.R. & Prefilter - 1500 CFM	2,640	---	---
(D)	C.B.R. & Prefilter - 300 CFM	---	400	400
(E)	Well-Water Pump - 6 g.p.m.	---	2,230	---
(F)	Well-Water Coil - 18" x 24" x 4 rows	---	280	---
(G)	Refrig. Comp. & A/C Cond. - 2.5 Tons	---	---	1,520
(H)	D.X. Coil - 18" x 24" x 2 rows	---	---	130
(I)	Engine Generator Set - 7.5 K.W.	2,200	2,200	---
(J)	Engine Generator Set - 10 K.W.	---	---	2,900
(K)	Fuel Tank - 14 Day	300	300	350
(L)	Lights, conduit and motor controls	840	860	900
(M)	Ducts, Piping, Supports and Partitions	700	610	780
	TOTAL	$7,000	$7,200	$7,300
	Cost per person	$ 70	$ 72	$ 73
	Blast Closures 35 or 60 psi	4	2	5
	Cost per person	$ 74	$ 74	$ 78

TABLE 6.8

Package Costs

(Including Heat Transfer)

250-Person Unit

CASE IV	VENT ONLY
CASE V	WELL-WATER COOLING
CASE VI	REFRIG. COOLING

		CASE IV	CASE V	CASE VI
(A)	Vent Fan - 3750 CFM	480	---	---
(B)	Vent & Recirc. Fan - 3750 CFM	---	480	480
(C)	C.B.R. & Prefilter - 3750 CFM	4,280	---	---
(D)	C.B.R. & Prefilter - 750 CFM	---	1,300	1,300
(E)	Well-Water Pump - 15 g.p.m.	---	2,300	---
(F)	Well-Water Coil - 24" x 30" x 4 rows	---	390	---
(G)	Refrig. Comp. & A/C Cond. - $6\frac{1}{2}$ Tons	---	---	2,670
(H)	D.X. Coil - 24" x 30" x 2 rows	---	---	230
(I)	Engine Generator Set - 15 K.W.	3,500	3,500	---
(J)	Engine Generator Set - 25 K.W.	---	---	3,900
(K)	Fuel Tank - 14 Day	400	400	450
(L)	Lights, conduit and motor controls	1,250	1,310	1,610
(M)	Ducts, Piping, Supports and Partitions	840	1,010	1,110
	TOTAL	$10,750	$10,750	$11,750
	Cost per person	$ 43	$ 43	$ 47
	Blast Closures 35 or 60 psi	4	2	4
	Cost per person	$ 47	$ 45	$ 51

TABLE 6.9

Package Costs

(Including Heat Transfer)

500-Person Unit

CASE IV	VENT ONLY
CASE V	WELL-WATER COOLING
CASE VI	REFRIG. COOLING

		CASE IV	CASE V	CASE VI
(A)	Vent Fan - 7500 CFM	770	---	---
(B)	Vent & Recirc. Fan - 7500 CFM	---	770	770
(C)	C.B.R. & Prefilter - 7500 CFM	6,500	---	---
(D)	C.B.R. & Prefilter - 1500 CFM	---	2,640	2,640
(E)	Well-Water Pump - 30 g.p.m.	---	2,600	---
(F)	Well-Water Coil - 30" x 42" x 4 rows	---	600	---
(G)	Refrig. Comp. & A/C Cond. - 13 Tons	---	---	5,140
(H)	D.X. Coil - 30" x 42" x 2 rows	---	---	420
(I)	Engine Generator Set - 25 K.W.	3,900	3,900	3,900
(J)	Engine Generator Set - ---	---	---	---
(K)	Fuel Tank - 14 Day	450	450	450
(L)	Lights, conduit and motor controls	2,020	1,950	2,310
(M)	Ducts, Piping, Supports and Partitions	1,800	1,590	1,870
	TOTAL	$15,500	$14,500	$17,500
	Cost per person	$ 31	$ 29	$ 35
	Blast Closures 35 or 60 psi	4	2	4
	Cost per person	$ 35	$ 31	$ 39

TABLE 6.10

Summary of Package Costs

(Dollars per person)

	WITHOUT HEAT TRANSFER CASE I	CASE II	CASE III	WITH MAXIMUM HEAT TRANSFER CASE IV	CASE V	CASE VI
100-PERSON UNIT						
Without Blast Closures	102	73	85	70	72	73
With Blast Closures	110	75	91	74	74	78
250-PERSON UNIT						
Without Blast Closures	58	44	50	43	43	47
With Blast Closures	66	46	56	47	45	51
500-PERSON UNIT						
Without Blast Closures	48	30	40	31	29	35
With Blast Closures	56	32	46	35	31	39

CASES I & IV - OUTSIDE AIR COOLING

CASES II & V - WELL-WATER COOLING

CASES III & VI - REFRIGERANT COOLING.

CBR filtering. Without this feature, such designs will be least expensive.

2 - With the filtering requirement, well-water cooled systems will result in least cost. Such systems also have least reliance on outside connections and are less cost-sensitive to overpressure criteria.

3 - Heat transfer through the shelter walls has most effect on outside-air cooled shelters and almost no effect on water-cooled shelters.

4 - On a per-capita basis, environmental control cost for a 500-person unit is approximately one-half that of a 100-person unit for the same type of system.

5 - For the arrangements considered, the optimum location (cost-wise) for mechanical-electrical equipment is within the shelter proper.

6.4 THE 24-HOUR CLOSURE PROBLEM

In this section we will consider closure requirements as they influence the heat transfer performance of the various shelter shapes.

6.4.1 SOLUTIONS TO THE O_2 - CO_2 PROBLEM

Table 6.11 lists some materials which can absorb CO_2 and/or provide oxygen. For the purposes of this analysis, two systems have been selected for study. They are:

1 - Bottled oxygen and Baralyme. (See Figure 6.73)

2 - Chlorate candles and Lithium Hydroxide. (See Figure 6.74)

The first system adds about 44 BTU/HR/Person to the shelter heat load and the second system adds about 197 BTU/HR/Person.

Two ways that CO_2 absorbents such as Baralyme or LiOH might be used are shown on Figures 6.75 and 6.76. The first method uses ordinary window screen on which the material is spread. The second is a cannister arrangement with an integral electric fan. If power is not available during closure, this system might be ar-

TABLE 6.11

SOME AGENTS FOR USE IN O_2-CO_2 SYSTEMS

AGENT	SENSIBLE HEAT LIBERATED BTU/LB	LATENT HEAT LIBERATED LB-H_2O/LB	TOTAL HEAT LIBERATED BTU/MAN-HR	CO_2 ABSORBED CU.FT./LB	O_2 LIBERATED CU.FT./LB
Bottled O_2	--	--	--	--	Supplied in Volume
Chlorate Candles	390	--	85	--	4.15
Baralyme	100	0.5	44	4.34	--
Lithium Hydroxide	1010	0.38	112	6.74	--
Sodium Superoxide	696	--	174	2.88	3.94
Potassium Tetroxide	480	--	175	2.28	3.27
Soda Lime	380	Some	129	2.82	--

ranged for manual operation.

A typical bottled-oxygen supply system is shown on Figure 6.77. Approximately one standard bottle is required per 10 shelterees. Chlorate candles are usually burned in a specially designed "furnace." At least one firm* is manufacturing chlorate candles for Civil Defense use and developing a low-cost furnace.

Additional data concerning O_2 - CO_2 systems can be found in References 1, 2, 6, 8, 9, 12, 17, 18 and 19.

6.4.2 ASSUMPTIONS

In order to simplify the heat transfer problem, we have made the following assumptions:

1 - Soil and shelter temperatures are initially equal.

2 - Heat is equally transferred to all surfaces.

3 - Configurations are semi-infinite slabs, surrounded by sufficient soil to absorb all heat.

6.4.3 PROCEDURES

Temperatures after 24 hours were calculated for "good" and "poor" soils and for each of the O_2 - CO_2 systems. Total heat input was changed by $\pm$ 100 BTU/HR/Person to determine the influence of variations in metabolic rate.

The method of solution involves a numerical approach using finite differences. (See Appendix D of Reference 1.)

6.4.4 RESULTS

Table 6.12 lists the calculated step functions and final air temperatures for the various configurations and Table 6.13 shows the effect of metabolic rate on final air temperature. These computed values were based on an initial temperature of 55F. If this should change by some value ΔT, the final air temperature can be

(text continued on page 134)

* Maywood Chemical Company, Maywood, New Jersey

TABLE 6.12

STEP FUNCTION f(T) AND FINAL TEMPERATURE INSIDE CONFIGURATIONS AFTER 24 HOURS

	(Constant Heat Input)							
	Step - Function F				Temp. Inside Shelter After 24 Hrs. - F			
	Ba + O_2		LiOH + Candles		Ba + O_2		LiOH + Candles	
Config.	G.S.	P.S.	G.S.	P.S.	G.S.	P.S.	G.S.	P.S.
IR	14.78	21.42	18.90	27.5	94.48	118.22	105.7	136.0
IA	11.50	16.72	14.78	21.42	85.90	104.62	94.78	118.62
ID	13.95	20.30	17.86	26.0	92.55	115.10	103.16	132.0
IH *	11.10	16.10	14.15	20.6	84.60	102.3	92.85	115.6
II R	18.45	26.80	23.6	34.3	104.35	133.28	118.2	156.3
II A	24.70	35.80	31.6	46.0	120.90	160.5	139.5	190.5
II D	27.30	39.60	34.9	50.8	128.0	171.9	148.5	204.5
III R	19.26	27.90	24.5	35.7	106.5	137.4	121.1	160.7
III A	32.40	48.50	42.7	62.0	142.4	198.0	169.5	238.0
III D	35.20	51.00	45.0	65.3	149.4	205.3	176.0	248.3

* Minimum Rectangular Cross-section

TABLE 6.13

EFFECT OF ACTIVITY ON FINAL AIR TEMPERATURE
BARALYME AND BOTTLED OXYGEN - GOOD SOIL @ 55F

(Constant Heat Input)

CONFIGURATION	-100 BTU/HR(444)	544BTU/HR	+100 BTU/HR(644)
I R	87.25	94.48	100.05
I A	80.20	85.90	90.35
I D	85.69	92.55	97.95
I H	79.15	84.60	89.90
II R	95.25	104.35	111.40
II A	108.70	120.90	130.30
II D	114.60	128.0	138.40
III R	97.10	106.5	113.90
III A	126.80	142.4	156.0
III D	131.80	149.4	162.8

closely approximated by adding ΔT.

The results of the time-temperature solutions are graphically shown on Figures 6.78 - 6.80. It is noted that some temperatures calculated are well beyond survivability limits. We do not suggest that such temperatures could ever be reached.

We also note that for configurations where survivability is possible, shelter temperatures rise sharply after closure and thereafter increase very slowly. Because of this and the many uncertainties involved, it seems reasonable to allow a margin of safety for planning purposes. That is, maximum closure temperature might be set at 85F* instead of 90F. The question may arise then as to the requirements to maintain this temperature. Assuming 500/BTU/HR/Person and using a Baralyme-Bottled Oxygen system, we found that approximately 32 sq. ft. of wall surface per person is required with "good" soil at 55F and approximately 53 sq. ft. of wall surface per person is required with "poor" soil at 55F.

6.4.5 CONCLUSIONS

Within the limitations of the assumptions and methods used, we can conclude the following:

1 - There is a significant performance difference between using Bottled Oxygen and Baralyme and using Chlorate Candles and Lithium Hydroxide. For some configurations the increased heat load inherent in the latter system may result in marginal survivability.

2 - The various configurations can be rated in terms of maximum closure performance as follows:

Rating	Configuration
1	Minimum Rectangular Cross-Section
2	100-person Arch

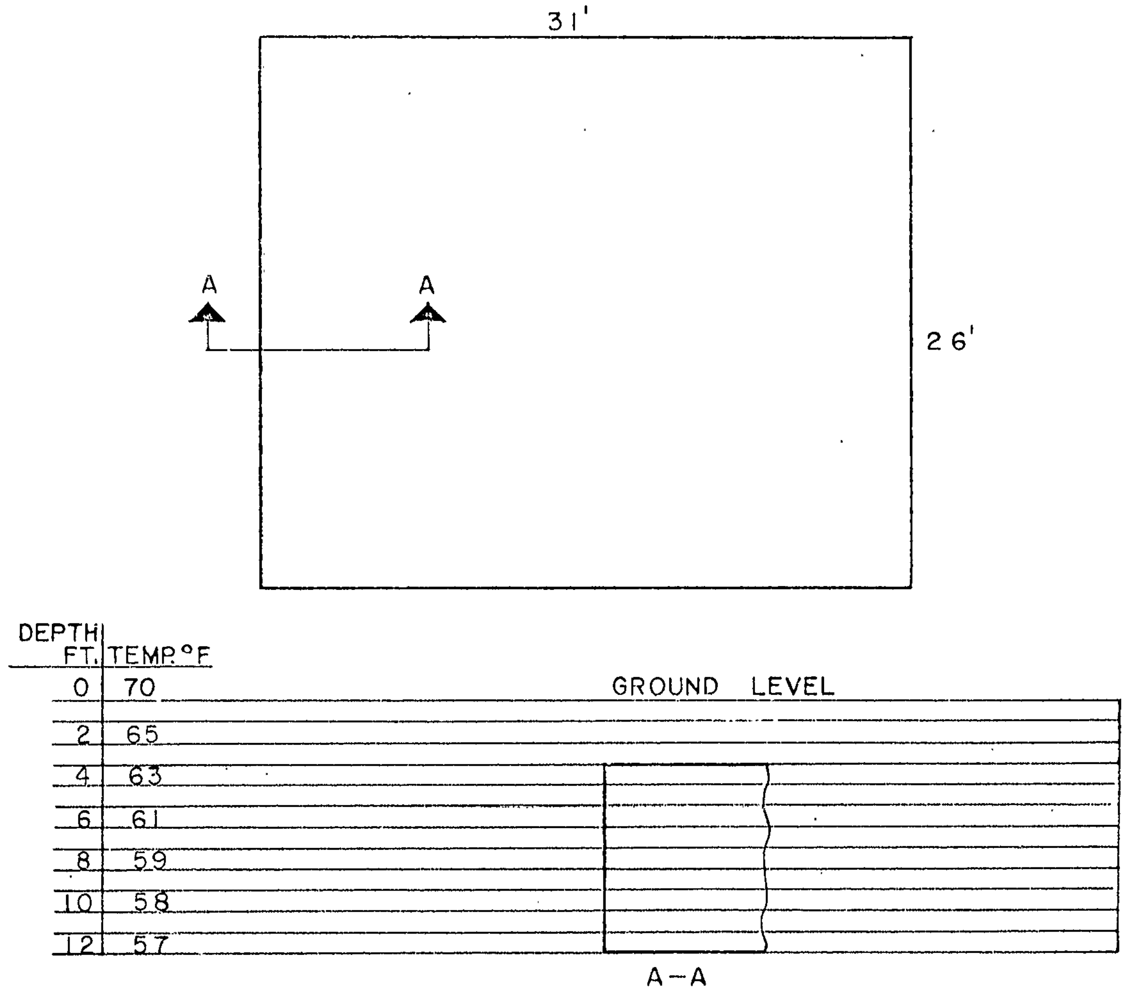
* Dry bulb or effective since the relative humidity will probably be close to 100%.

Rating	Configuration
3	100-person Dome
4	100-person Rectangle
5	500-person Rectangle
6	1000-person Rectangle
7	500-person Arch
8	500-person Dome
9	1000-person Arch
10	1000-person Dome

Ratings in terms of closure time for optimum configurations are given in Section 7.

3 - If a minimum cross-section configuration is not used or the configuration has less than about 35 square feet to wall surface per person or the soil conditions are not ideal, some other means must be available for heat dissipation for a 24-hour closure period. Otherwise, the allowable closure time shortens.

(text continued on page 176.)



100 MAN RECTANGULAR CONFIGURATION

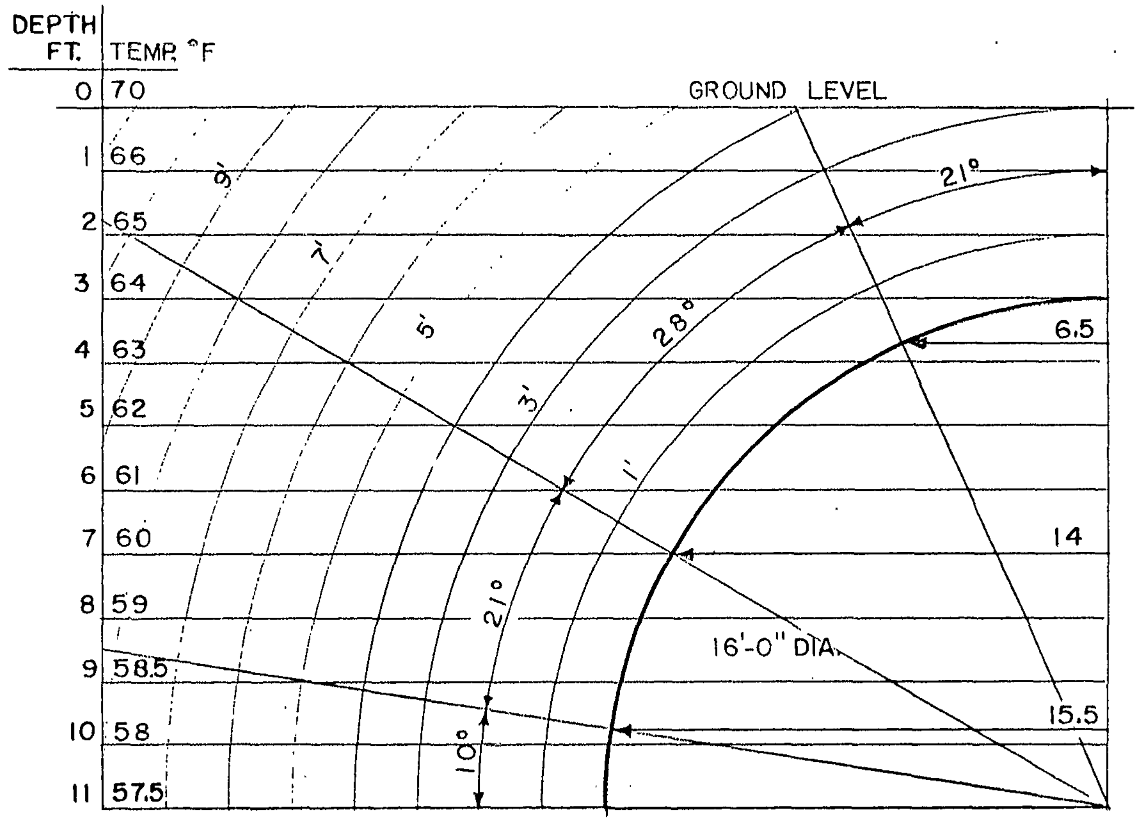
805 : 3'-0", "ACTUAL" SOIL TEMPERATURE

832 : 18'-0", SOIL TEMPERATURE 60° F

805 : 18'-0", SOIL TEMPERATURE 55° F

2442 SQ. FT. TOTAL AREA

FIG. 6.1



100 MAN ARCH CONFIGURATION — I A

1448 : 18'-0", SOIL TEMPERATURE 55°F

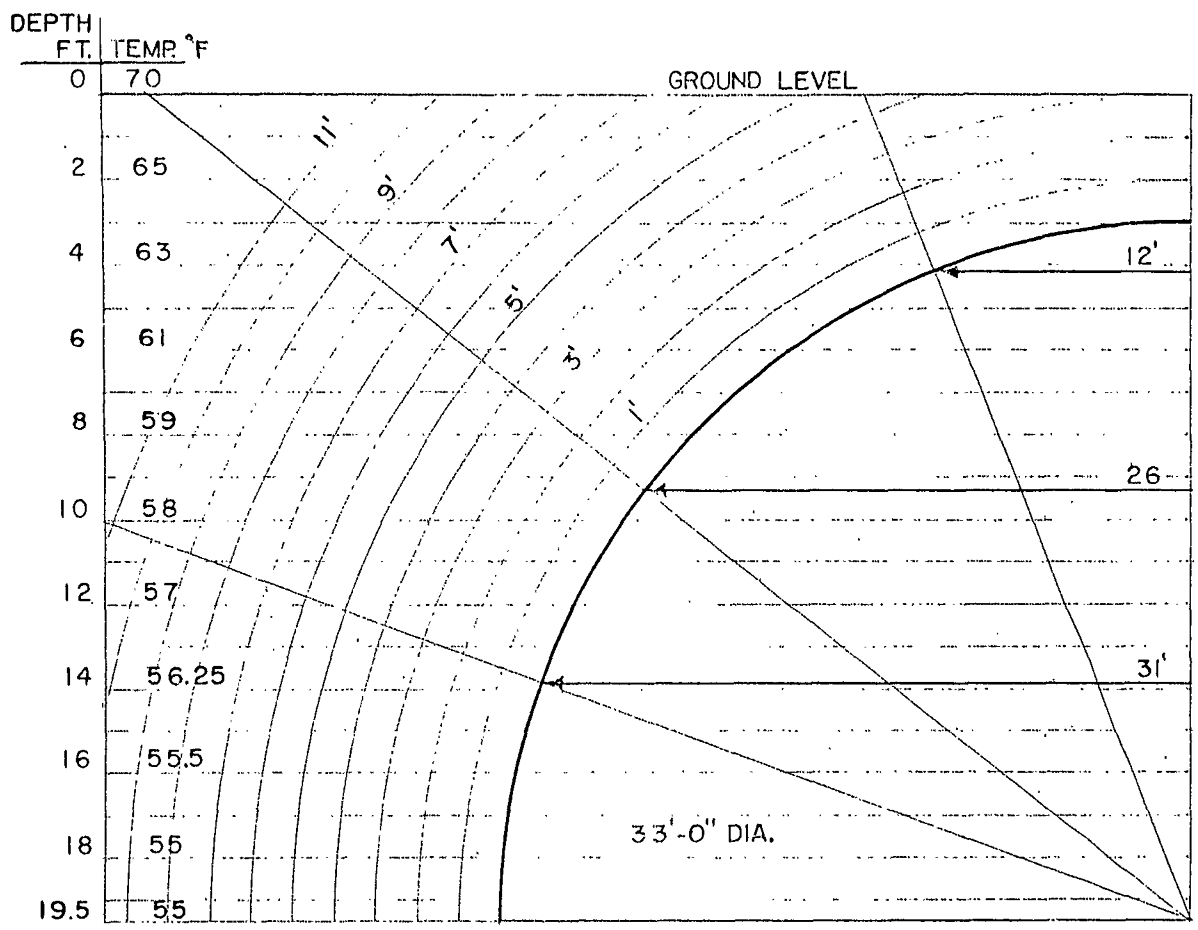
510 : 18'-0", SOIL TEMPERATURE 60°F

838 : 8'-0", SOIL TEMPERATURE 65°F

417 : 3'-0", "ACTUAL" SOIL TEMPERATURE

3213 SQ.FT. TOTAL AREA

FIG. 6.2

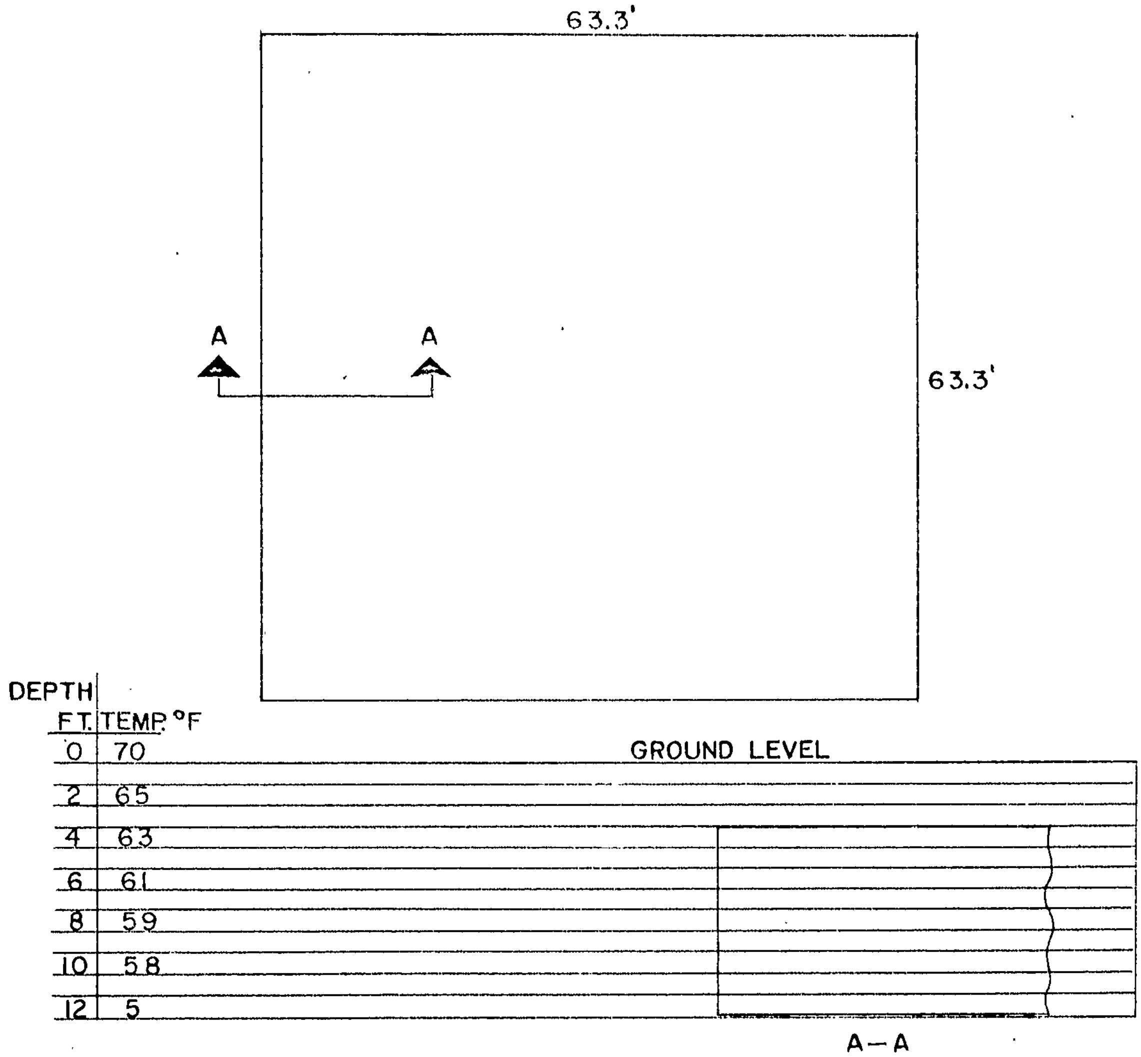


100 MAN DOME CONFIGURATION — I D

1558 : 18'-0", SOIL TEMPERATURE 55°F
356 : 18'-0", SOIL TEMPERATURE 60°F
520 : 8'-0", SOIL TEMPERATURE 65°F
126 : 3'-0", "ACTUAL" SOIL TEMPERATURE

2560 SQ.FT. TOTAL AREA

FIG. 6.3



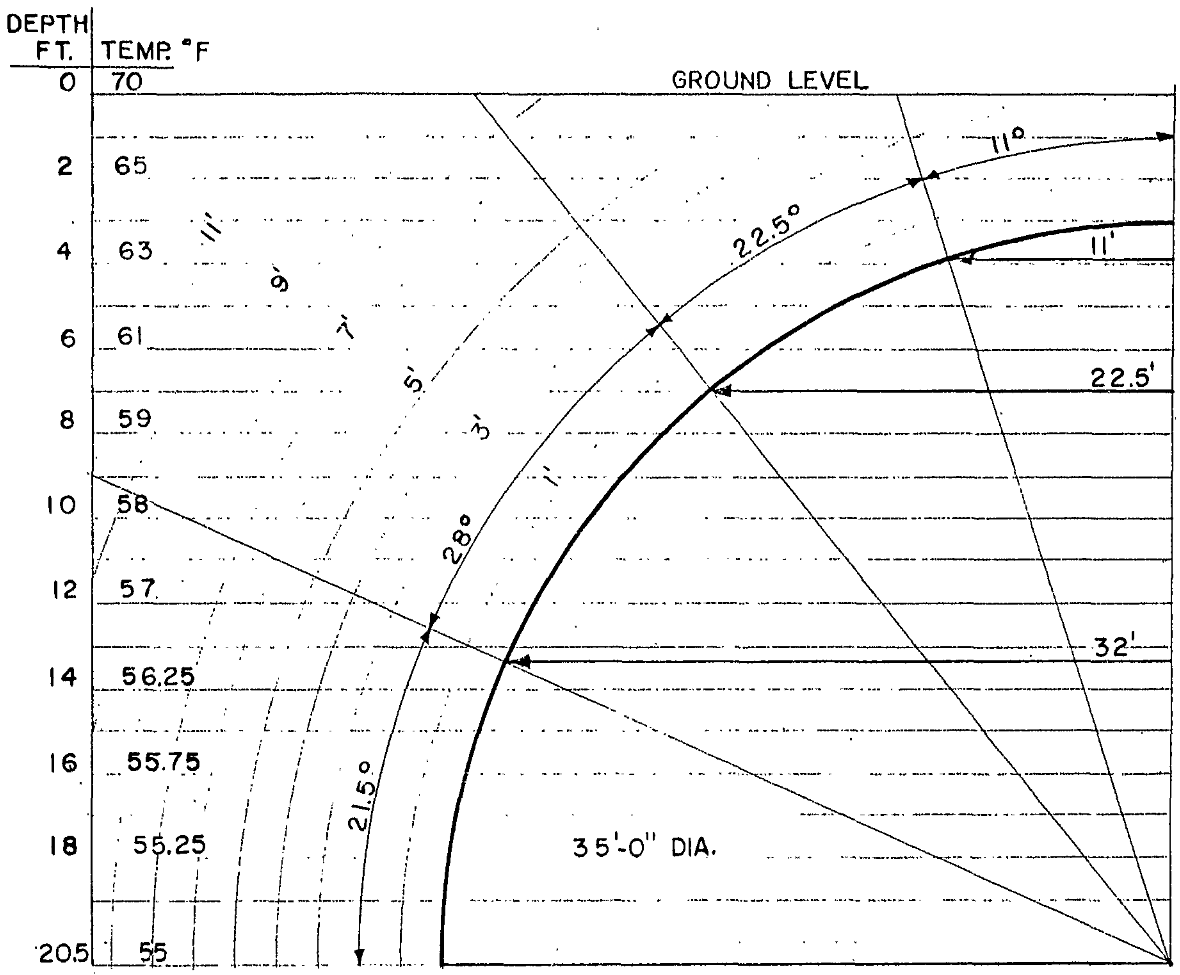
500 MAN RECTANGULAR CONFIGURATION

II R

3970 : 3'-0", "ACTUAL" SOIL TEMPERATURE
1842 : 18'-0", SOIL TEMPERATURE 60°F
3970 : 18'-0", SOIL TEMPERATURE 55°F

9782 SQ. FT. TOTAL AREA

FIG. 6.4

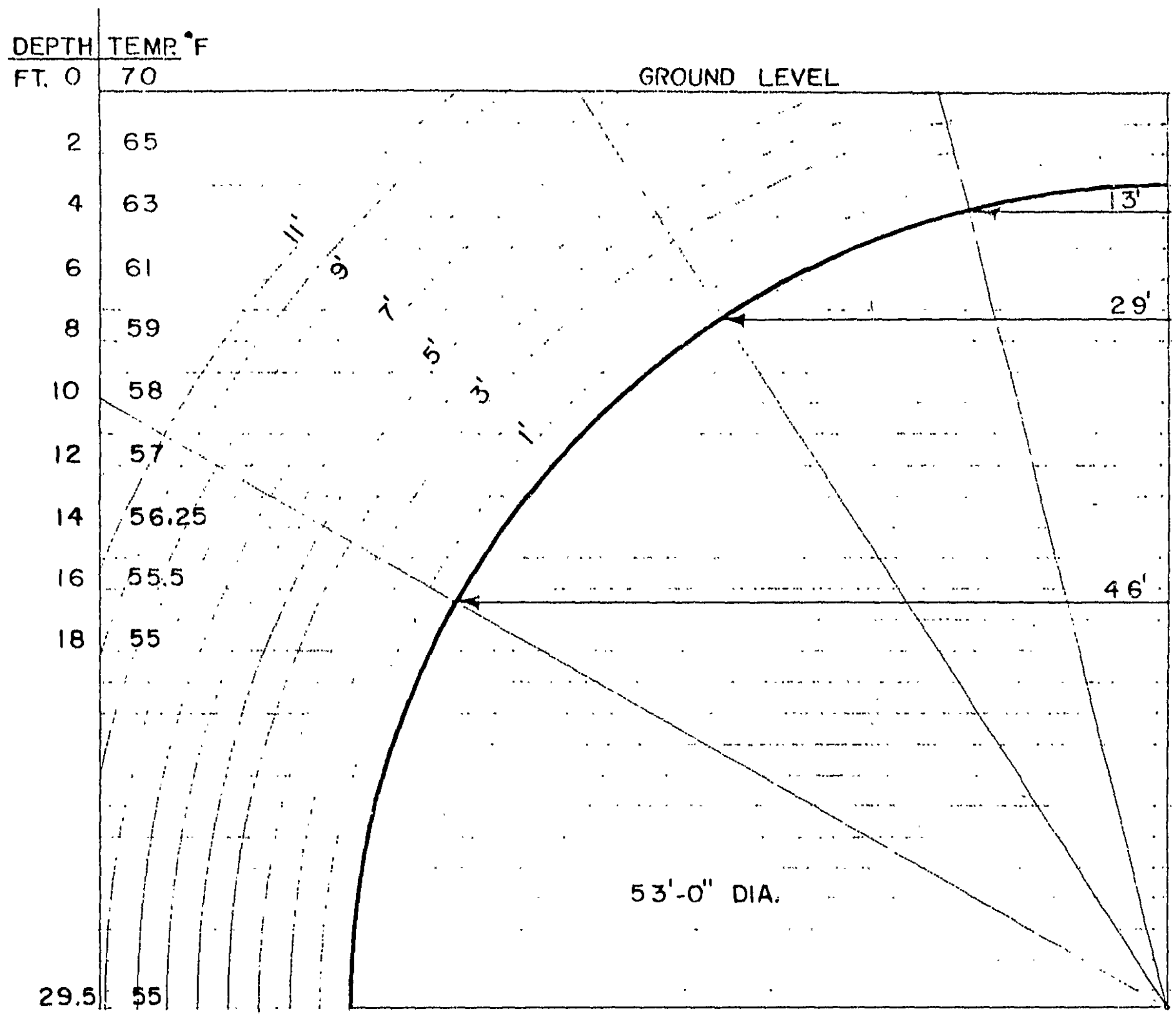


500 MAN ARCH CONFIGURATION — II A

4080 :	18'-0",	SOIL TEMPERATURE 55° F
1535 :	18'-0",	SOIL TEMPERATURE 60° F
1065 :	8'-0",	SOIL TEMPERATURE 60° F
777 :	3'-0",	"ACTUAL" SOIL TEMPERATURE

7457 SQ.FT. TOTAL AREA

FIG. 6.5

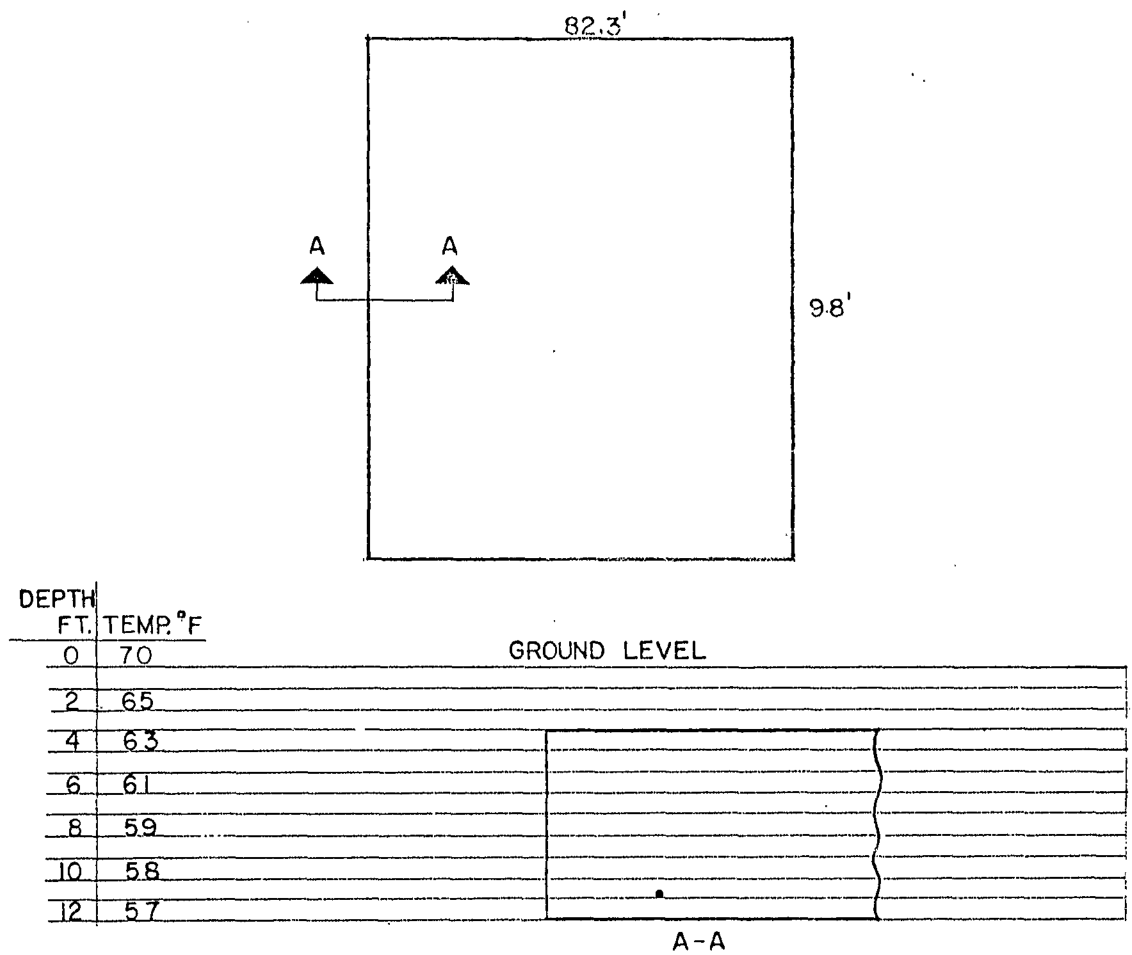


500 MAN DOME CONFIGURATION — II D

4400 : 18'-0", SOIL TEMPERATURE 55°F
1500 : 18'-0", SOIL TEMPERATURE 60°F
560 : 8'-0", SOIL TEMPERATURE 65°F
140 : 3'-0", "ACTUAL" SOIL TEMPERATURE

6600 SQ. FT. TOTAL AREA

FIG. 6.6

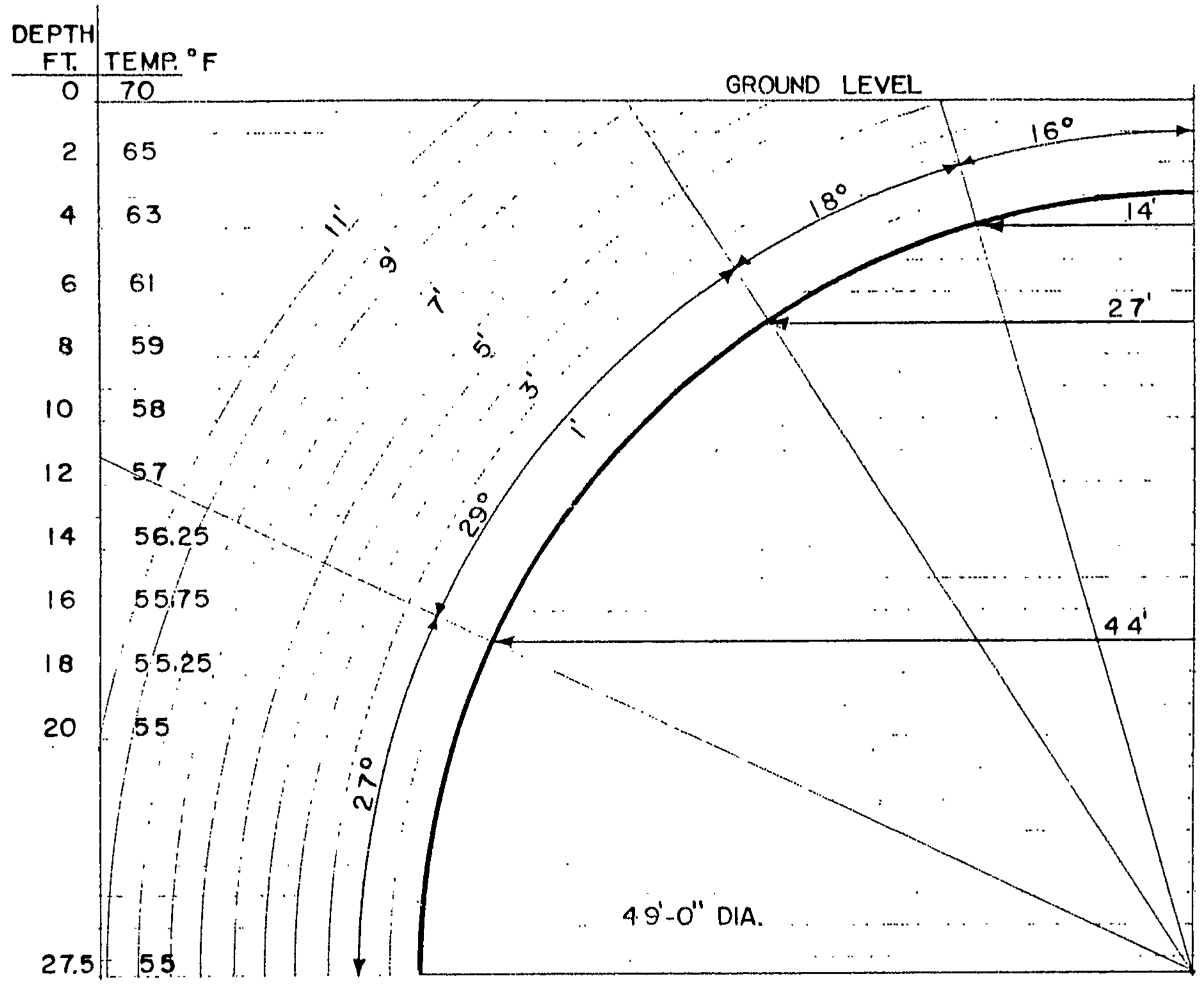


1000 MAN RECTANGULAR CONFIGURATION — III R

8070 : 3'-0", "ACTUAL" SOIL TEMPERATURE
2560 : 18'-0", SOIL TEMPERATURE 60°F
8070 : 18'-0", SOIL TEMPERATURE 55°F

18700 SQ.FT. TOTAL AREA

FIG. 6.7

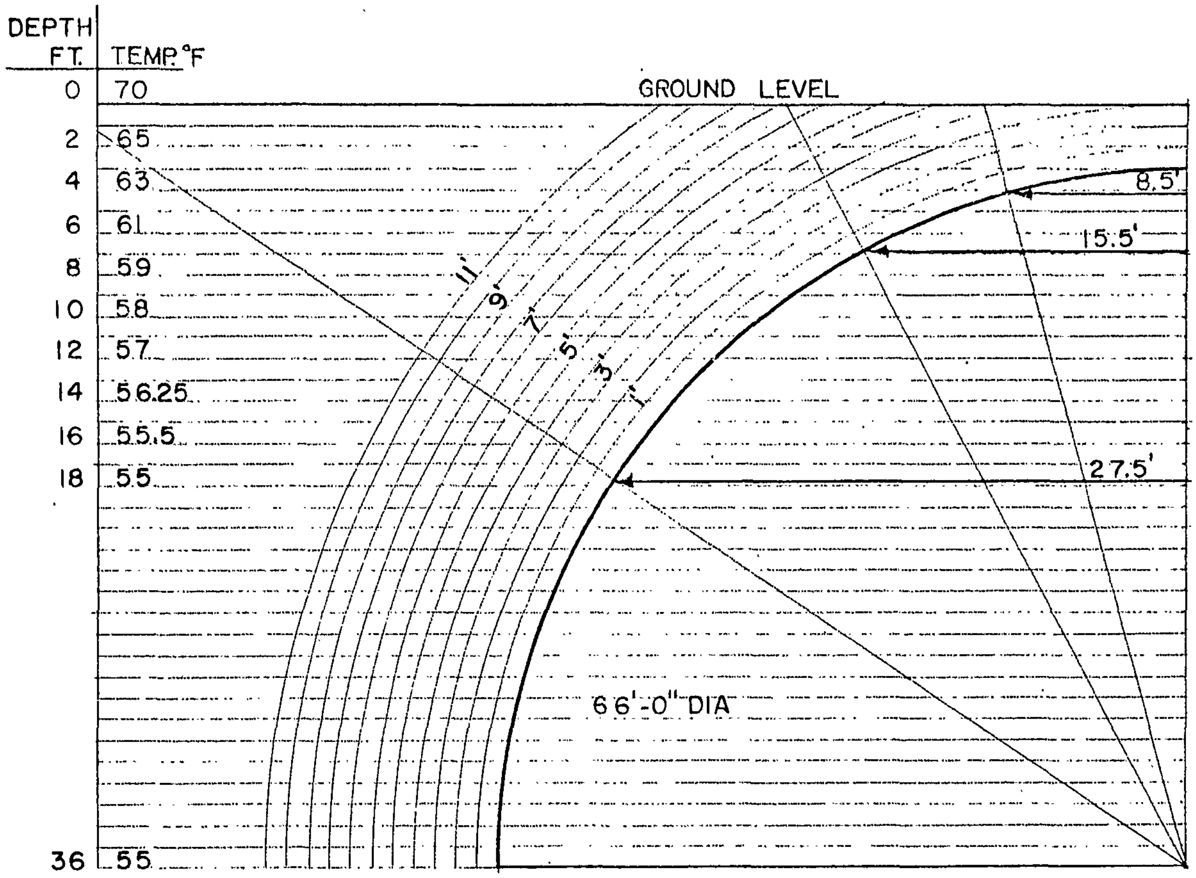


1000 MAN ARCH CONFIGURATION — III A

6090 : 18'-0", SOIL TEMPERATURE 55° F
2485 : 18'-0", SOIL TEMPERATURE 60° F
1230 : 8'-0", SOIL TEMPERATURE 65° F
975 : 3'-0", "ACTUAL" SOIL TEMPERATURE

10780 SQ.FT. TOTAL AREA

FIG. 6.8

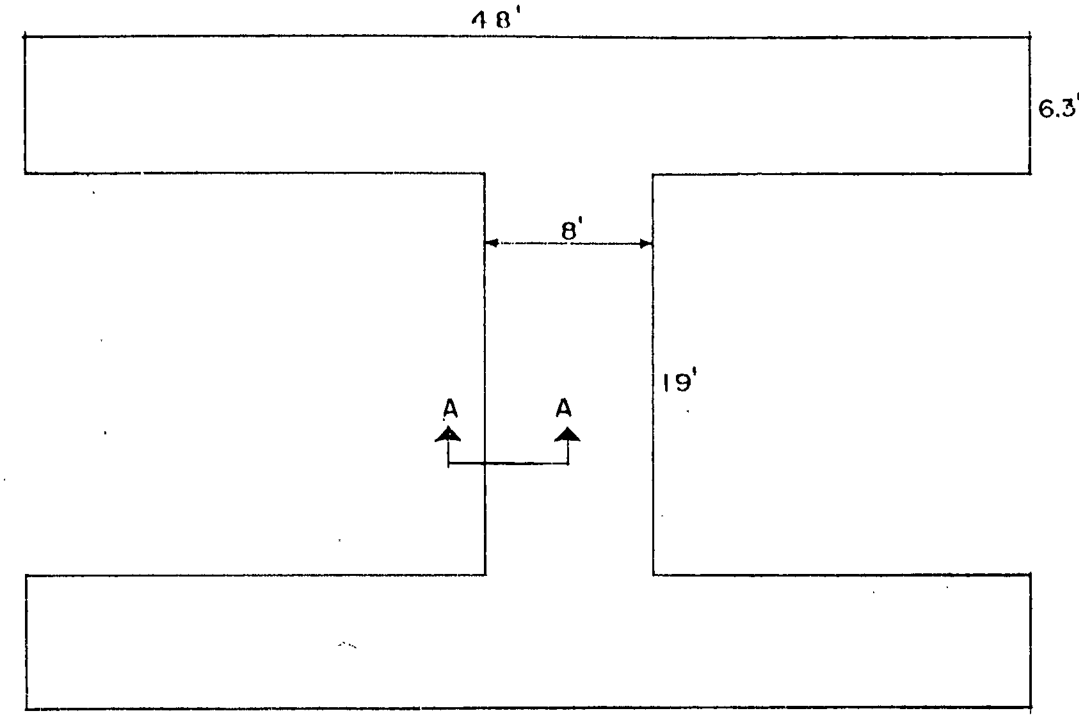


1000 MAN DOME CONFIGURATION — III D

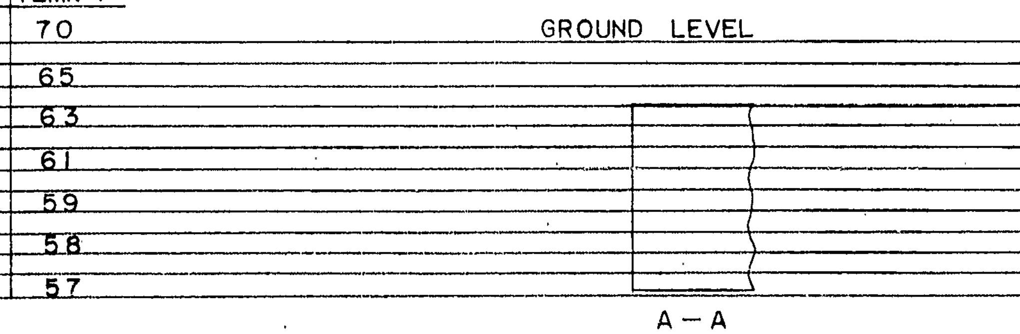
7125 : 18'-0", SOIL TEMPERATURE 55°F
2300 : 18'-0", SOIL TEMPERATURE 60°F
600 : 8'-0", SOIL TEMPERATURE 65°F
250 : 3'-0", "ACTUAL" SOIL TEMPERATURE

10275 SQ.FT. TOTAL AREA

FIG. 6.9



DEPTH FT.	TEMP. °F
0	70
2	65
4	63
6	61
8	59
10	58
12	57



MINIMUM CROSS SECTION

760 : 3'-0", "ACTUAL" SOIL TEMPERATURE
1750 : 18'-0", SOIL TEMPERATURE 60°F
760 : 18'-0", SOIL TEMPERATURE 55°F

2270 SQ. FT. TOTAL AREA

FIG. 6.10

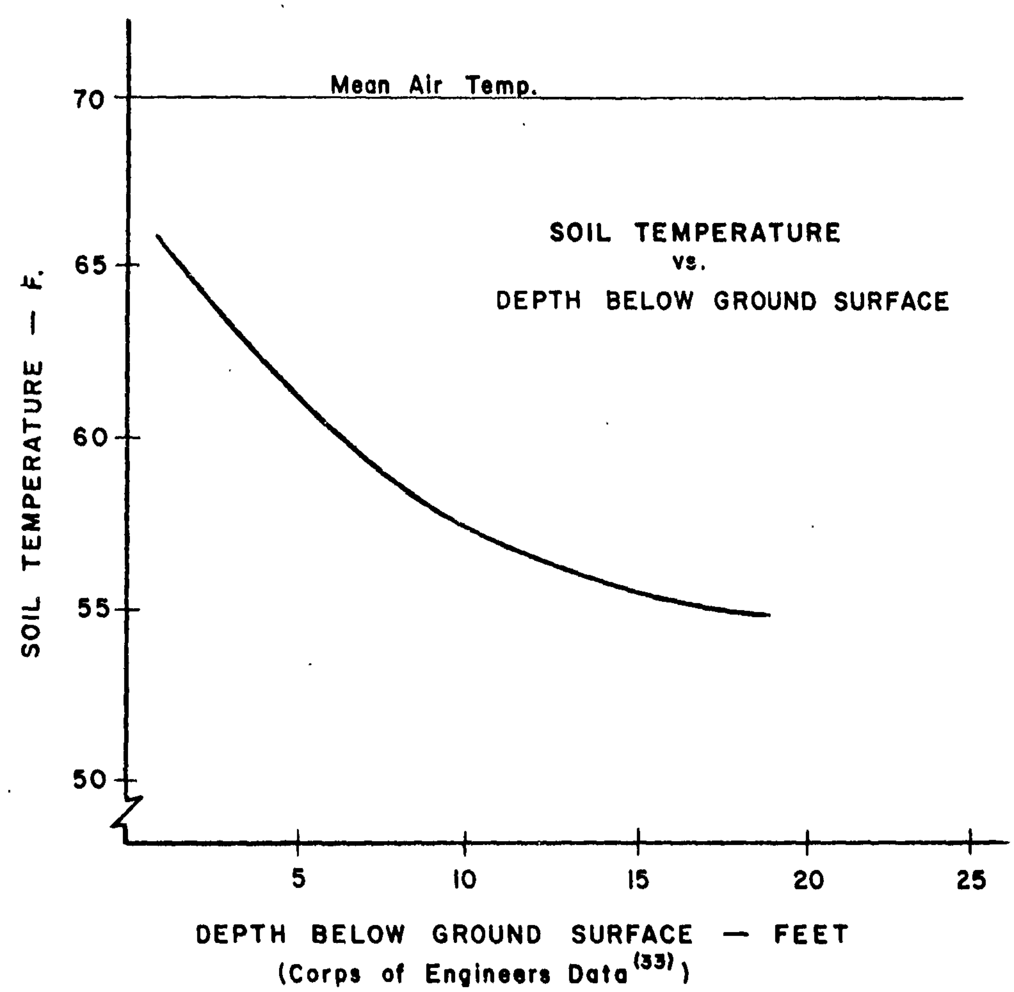
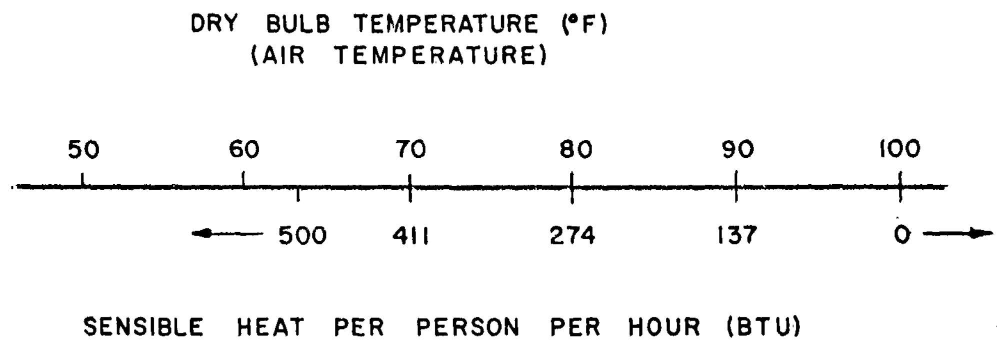

Mean Air Temp.
70
65
60
55
50
SOIL TEMPERATURE — F.
SOIL TEMPERATURE
vs.
DEPTH BELOW GROUND SURFACE
5
10
15
20
25
DEPTH BELOW GROUND SURFACE — FEET
(Corps of Engineers Data[33])

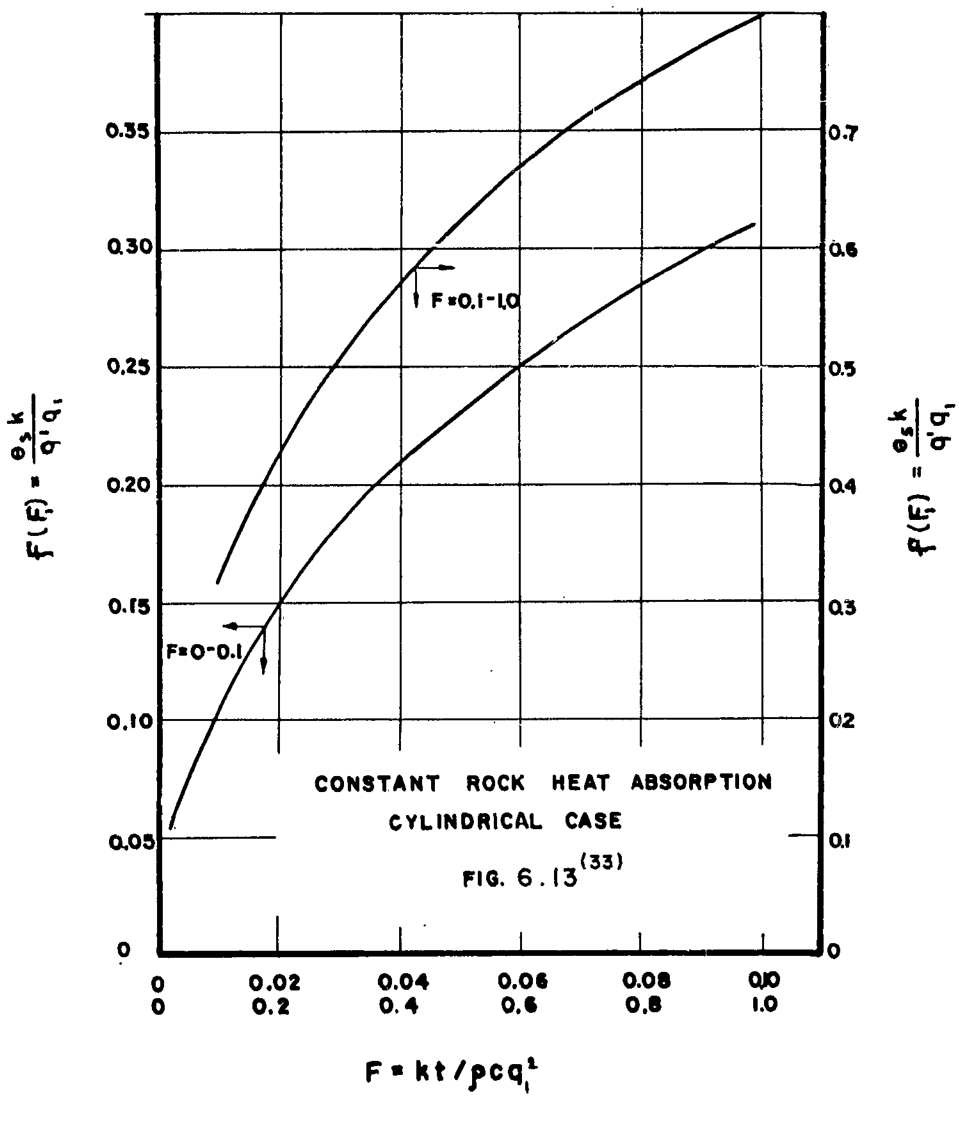
FIG. 6.11



$Q_L = 13.7\,(T_{DB} - 63.5)$ LATENT HEAT

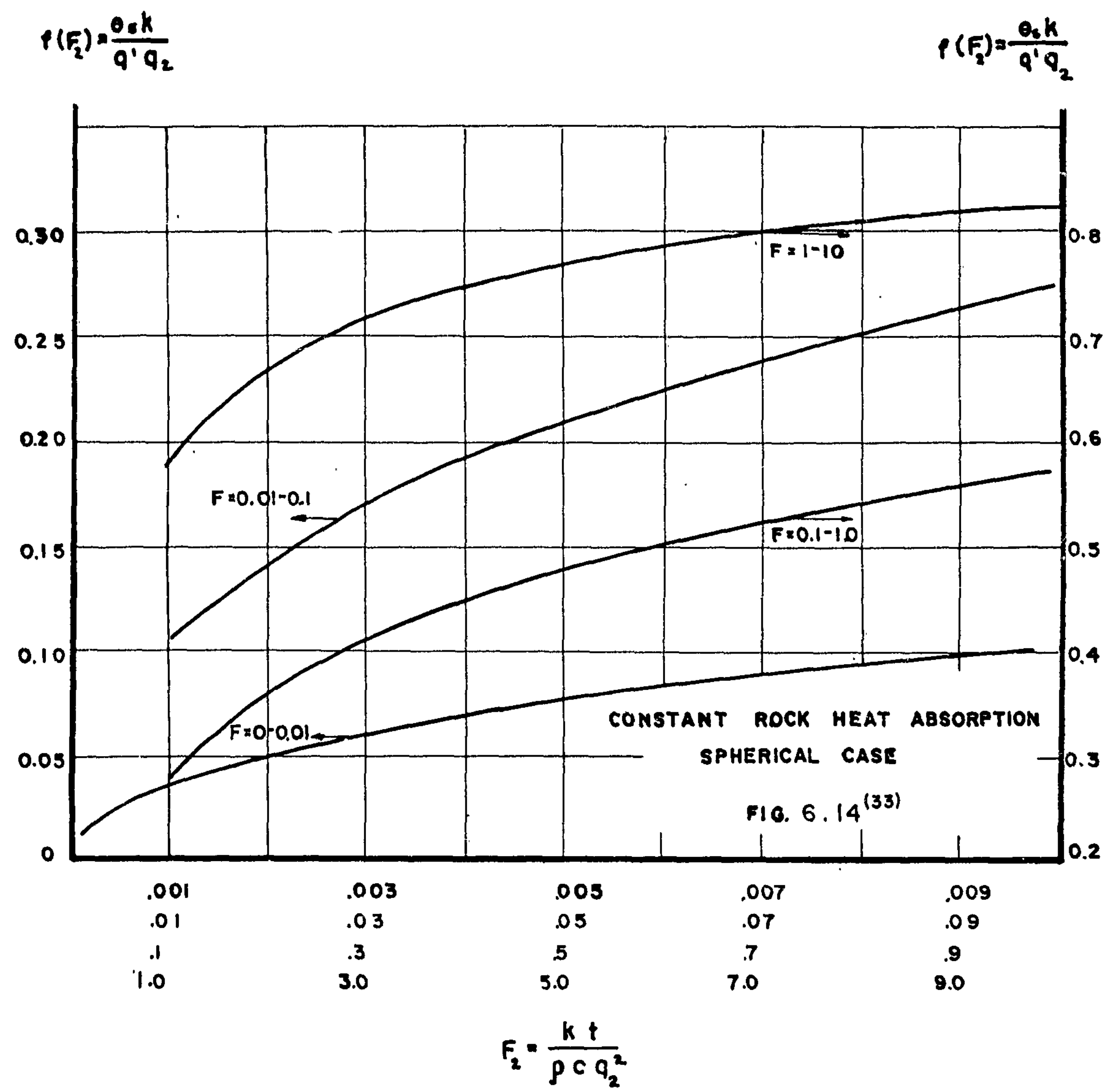
$Q_S = 13.7\,(100 - T_{DB})$ SENSIBLE HEAT

FIG. 6.12



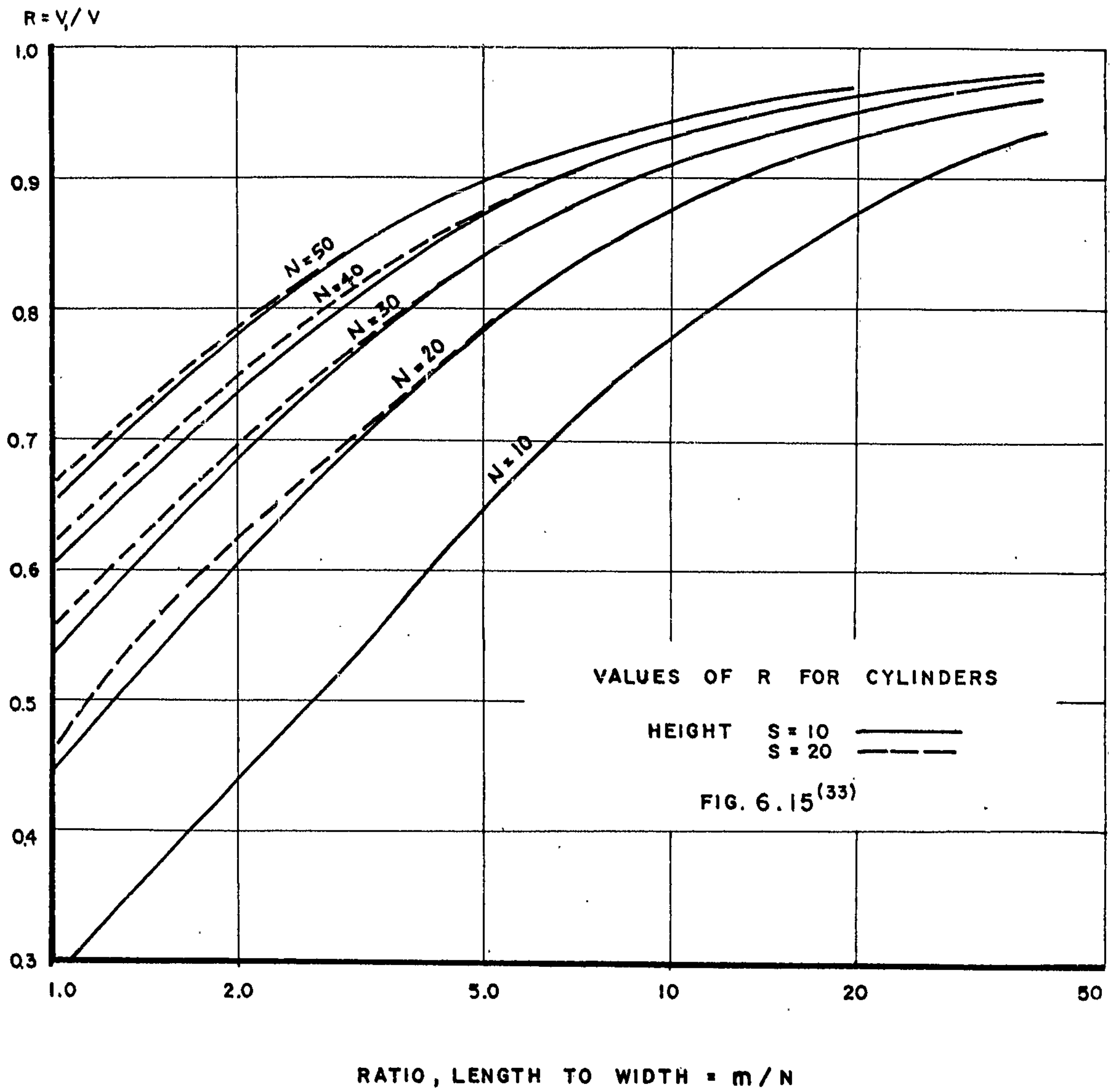
CONSTANT ROCK HEAT ABSORPTION
CYLINDRICAL CASE

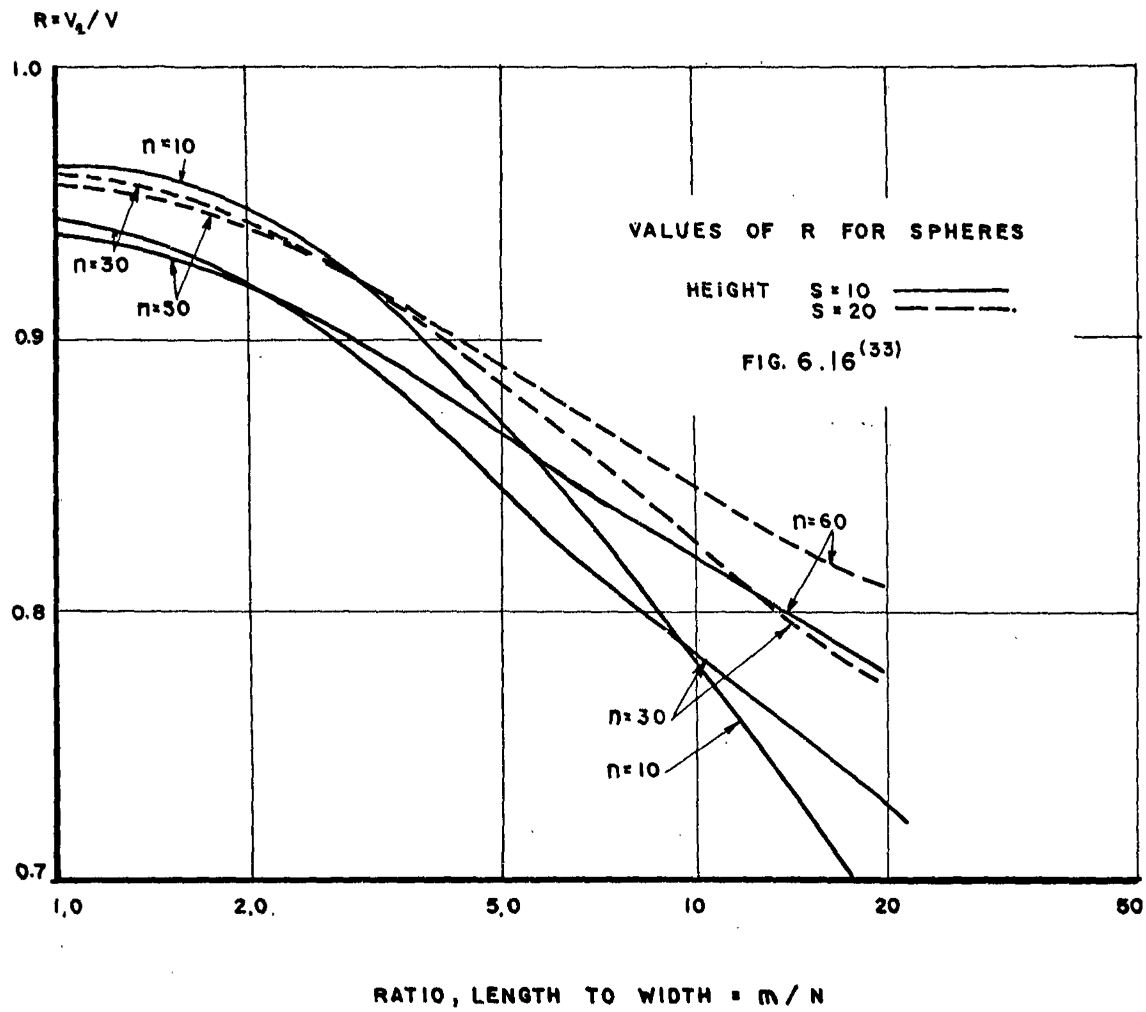
FIG. 6.13[33]



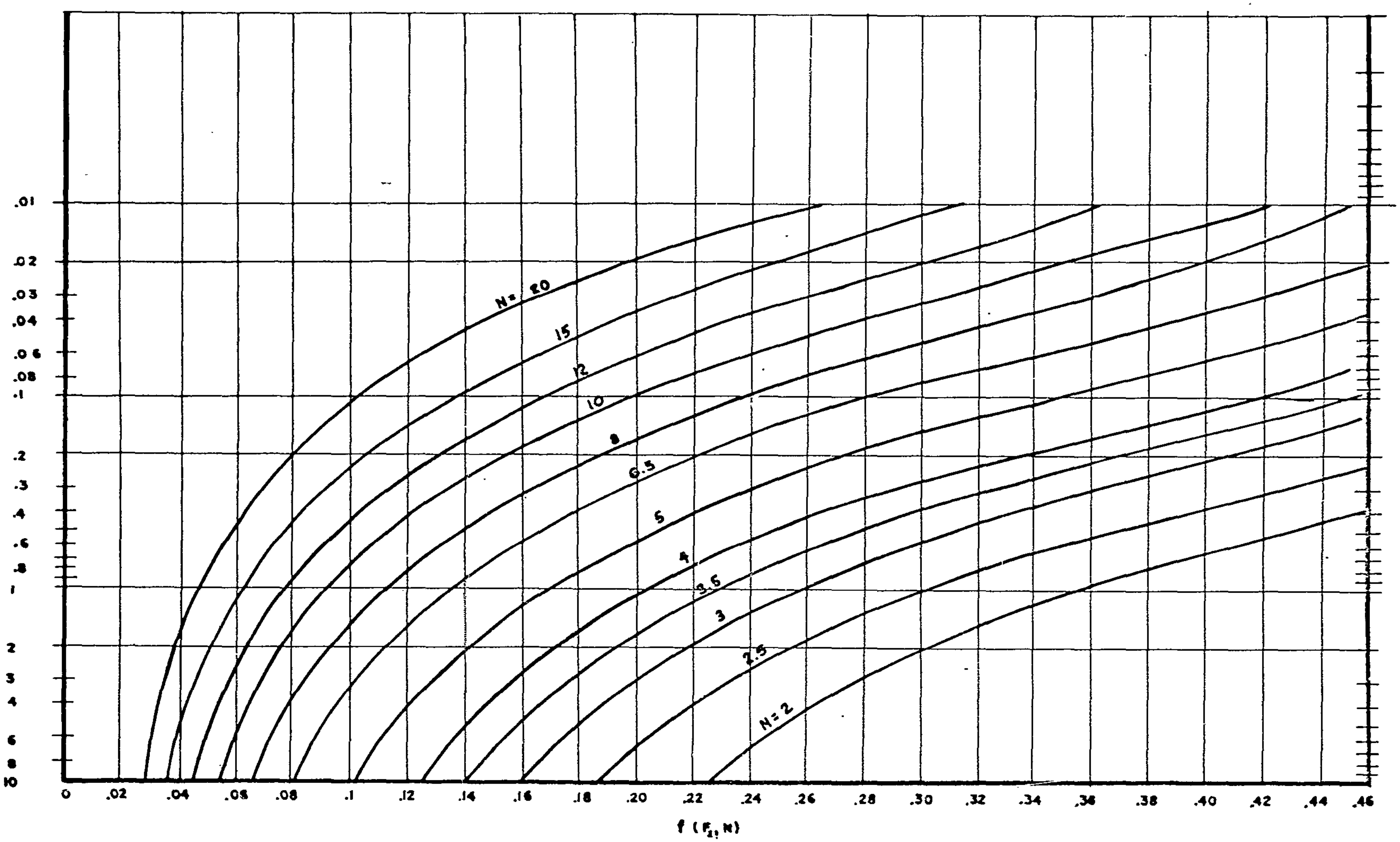
$f(F_2) = \frac{\theta_s k}{q' q_2}$
$f(F_2) = \frac{\theta_s k}{q' q_2}$
0.30
0.25
0.20
0.15
0.10
0.05
0
0.8
0.7
0.6
0.5
0.4
0.3
0.2
F = 1-10
F=0.01-0.1
F=0.1-1.0
F=0-0.01
CONSTANT ROCK HEAT ABSORPTION
SPHERICAL CASE
.001 .003 .005 .007 .009
.01 .03 .05 .07 .09
.1 .3 .5 .7 .9
1.0 3.0 5.0 7.0 9.0
$F_2 = \frac{k t}{\rho c q_2^2}$

FIG. 6.14[33]


R = V_1/V
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
1.0
2.0
5.0
10
20
50
N = 50
N = 40
N = 30
N = 20
N = 10
VALUES OF R FOR CYLINDERS
HEIGHT S = 10
S = 20
FIG. 6.15[33]
RATIO, LENGTH TO WIDTH = m / N

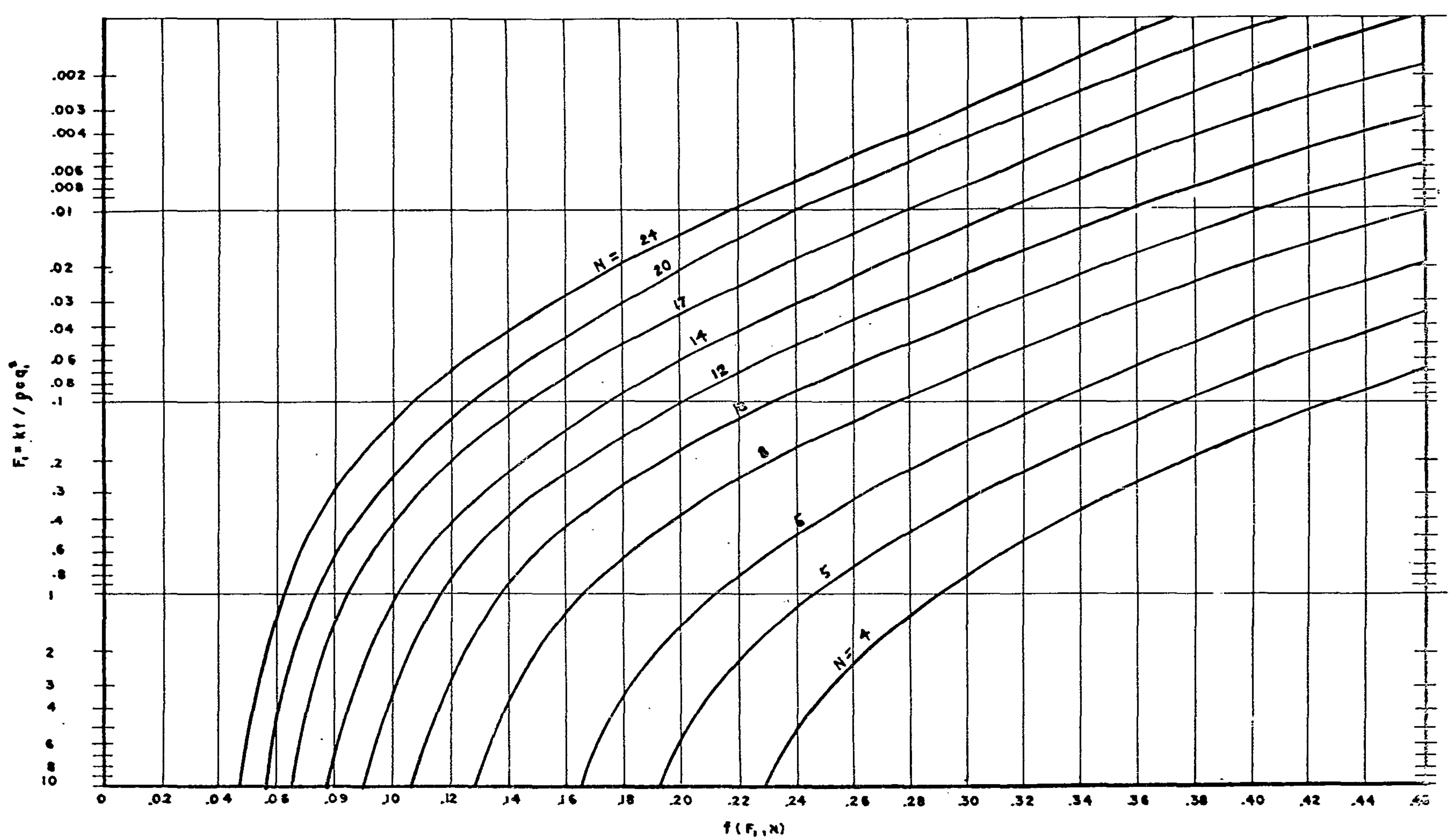


$R = V_1/V$
1.0
0.9
0.8
0.7
n=10
n=30
n=30
VALUES OF R FOR SPHERES
HEIGHT S=10
S=20
FIG. 6.16(33)
n=60
n=30
n=10
1,0
2,0
5,0
10
20
50
RATIO, LENGTH TO WIDTH = m/N



ROCK SURFACE TEMPERATURE WITH CONSTANT AIR TEMPERATURE, CYLINDRICAL CASE.

FIG. 6.17[33]



ROCK SURFACE TEMPERATURE WITH CONSTANT AIR TEMPERATURE . SPHERICAL CASE.

FIG. 6.18[33]

AIR FILM COEFFICIENT FOR CONCRETE SURFACES
AT 20°F MEAN TEMPERATURE[21]

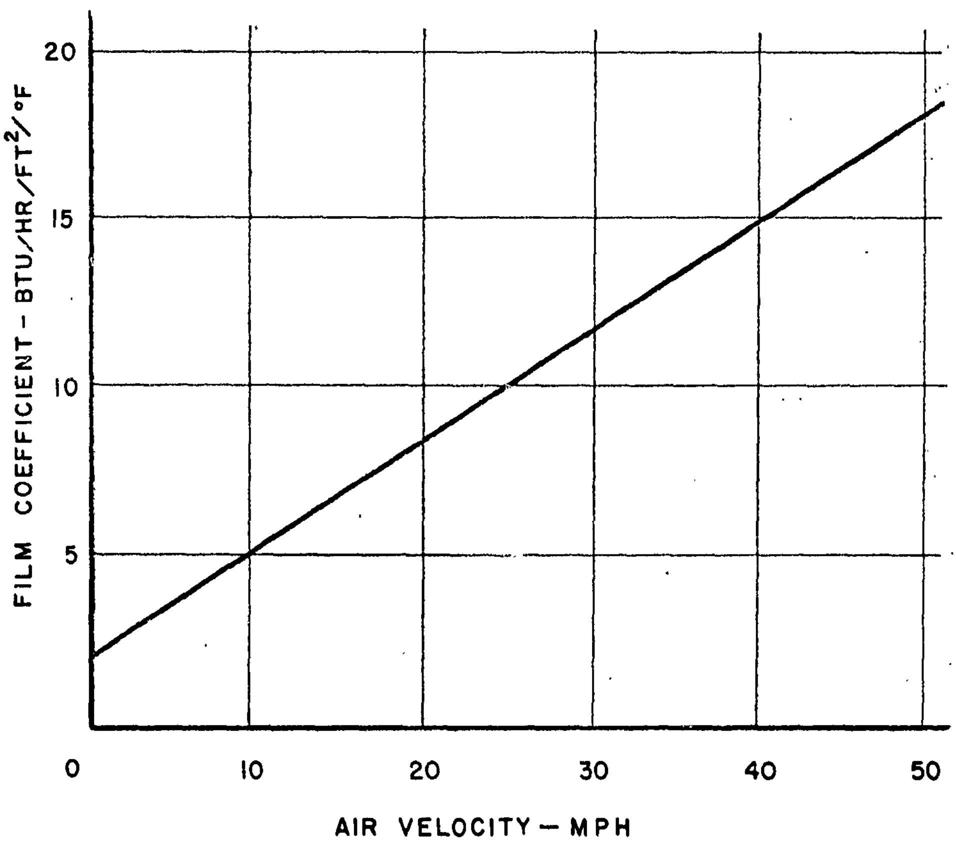
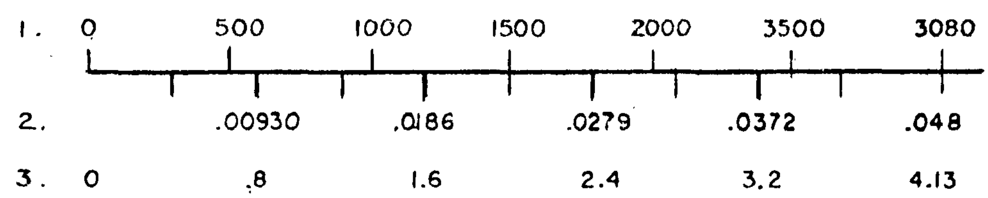


FIG. 6.19

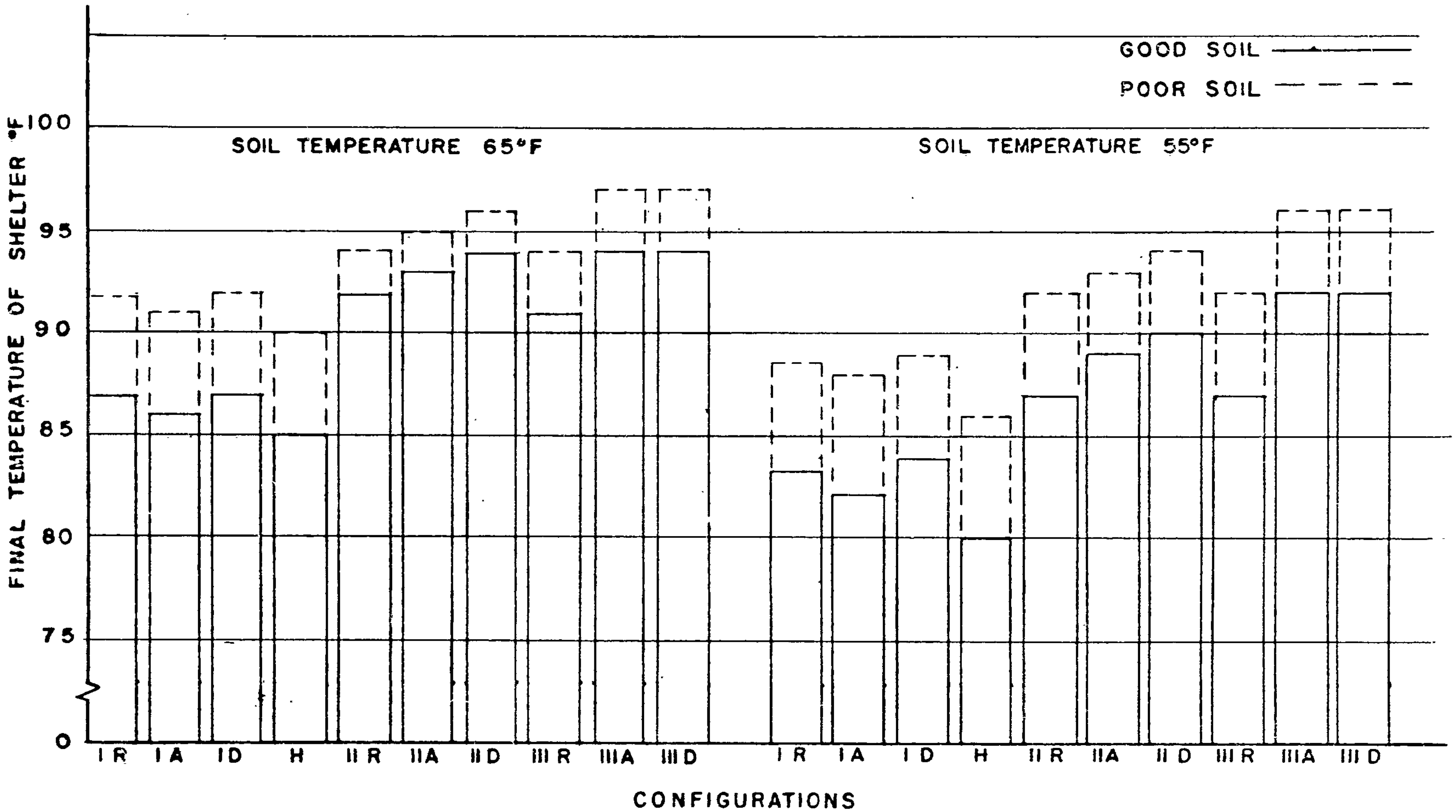


1. VELOCITY OF AIR INSIDE SHELTER — FT/MIN

2. INCREASE IN BTUS ABSORBED IN SOIL, DUE TO THE INCREASE IN AIR VELOCITY — BTU/HR-FT²-°F

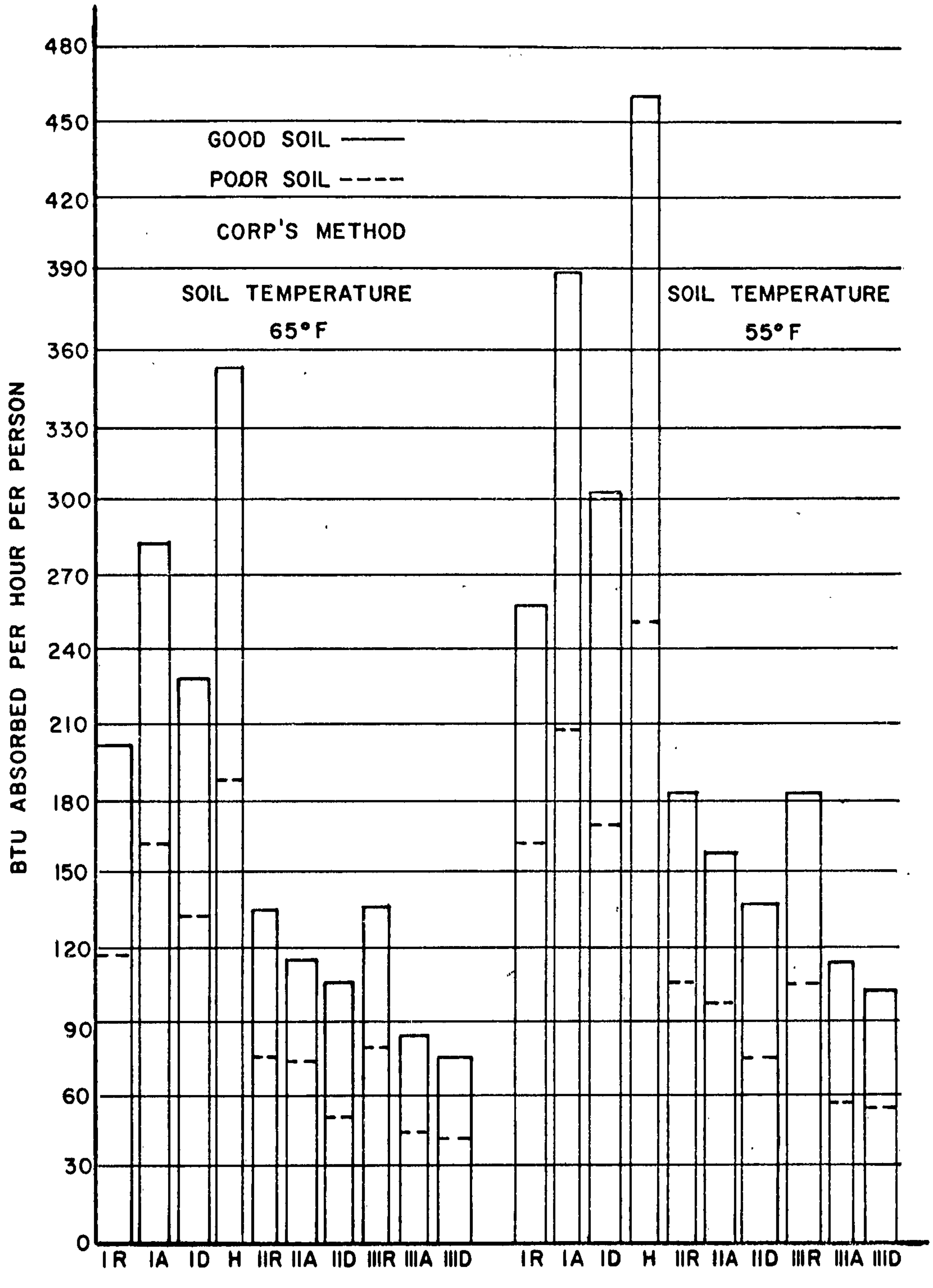
3. DECREASE IN SHELTER TEMPERATURE, DUE TO THE INCREASE IN AIR VELOCITY — °F

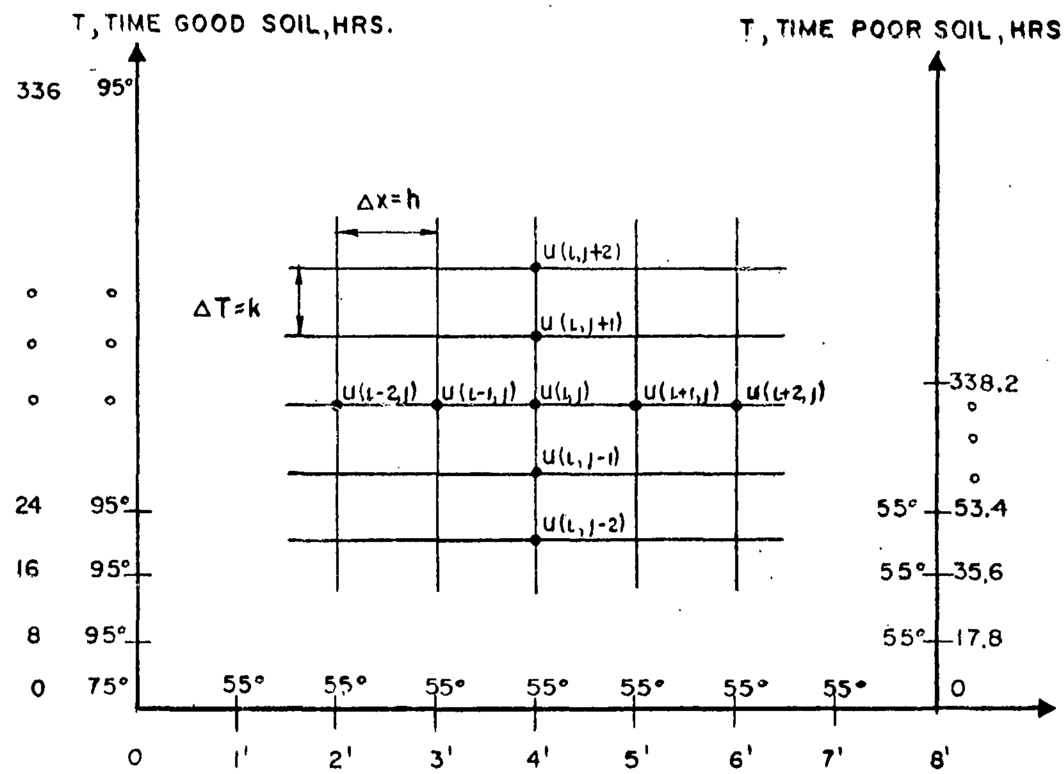
FIG. 6.20



SHELTER TEMPERATURE AFTER 14 DAYS

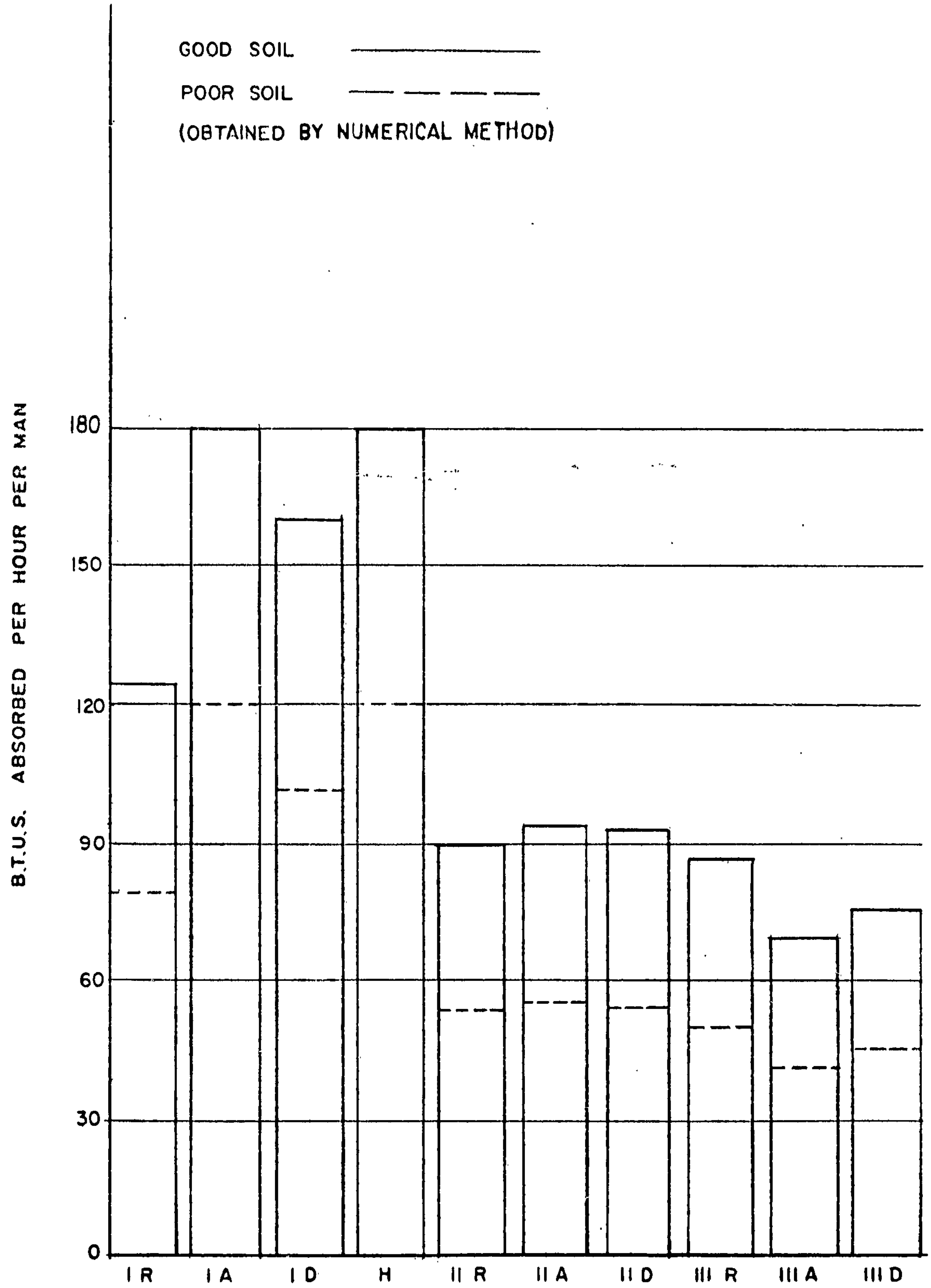
FIG. 6.41

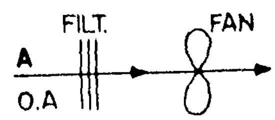

GOOD SOIL
POOR SOIL
CORP'S METHOD
SOIL TEMPERATURE 65°F
SOIL TEMPERATURE 55°F
BTU ABSORBED PER HOUR PER PERSON
480
450
420
390
360
330
300
270
240
210
180
150
120
90
60
30
0
IR IA ID H IIR IIA IID IIIR IIIA IIID IR IA ID H IIR IIA IID IIIR IIIA IIID
CONFIGURATIONS
FIG. 6.52



NUMERICAL METHOD GRID

FIG. 6.53


GOOD SOIL
POOR SOIL
(OBTAINED BY NUMERICAL METHOD)
B.T.U.S. ABSORBED PER HOUR PER MAN
180
150
120
90
60
30
0
I R
I A
I D
H
II R
II A
II D
III R
III A
III D
CONFIGURATIONS
FIG.6.64



VENTILATION ONLY
EXCLUDING HEAT TRANSFER

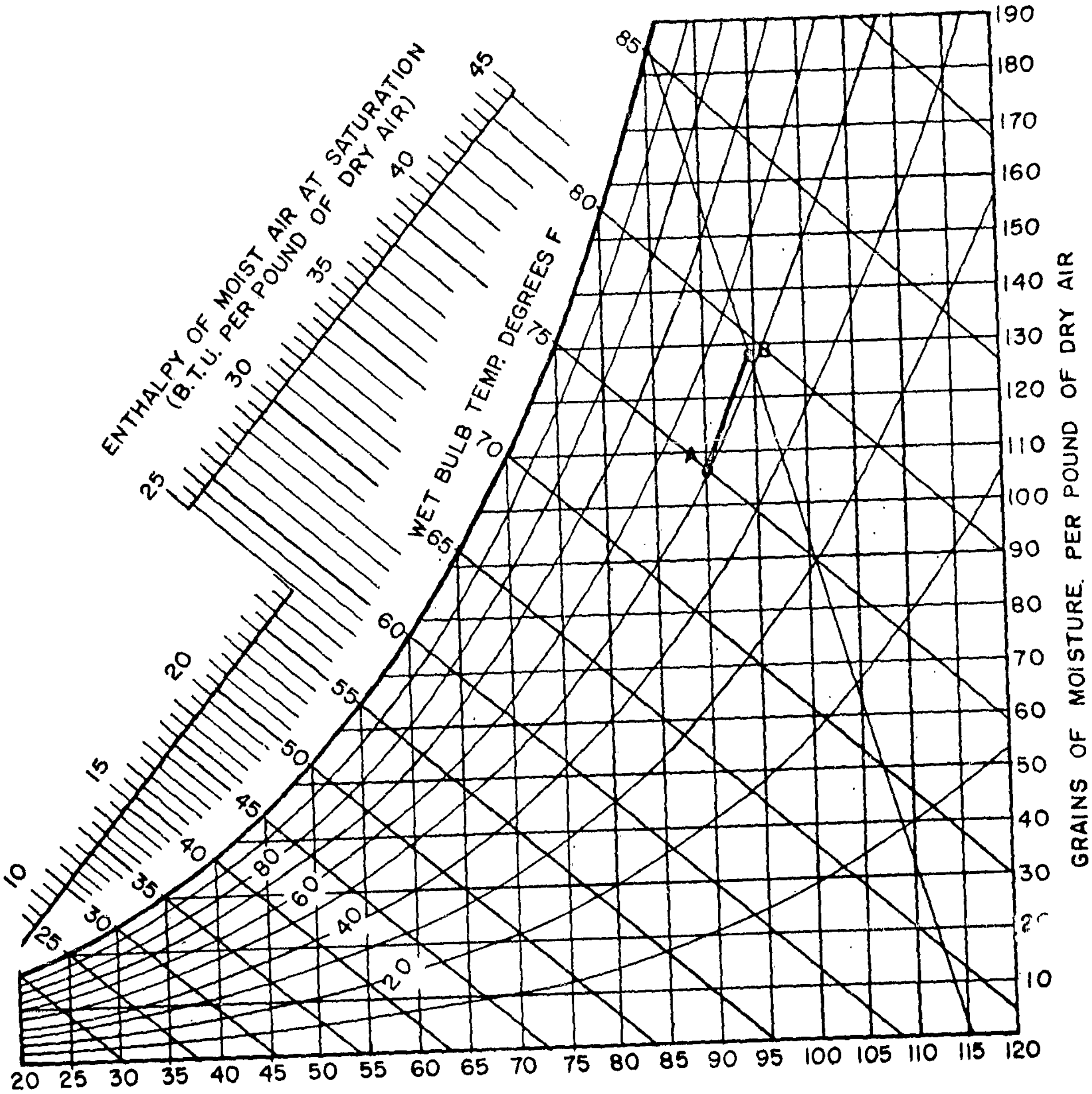


FIG. 6.65

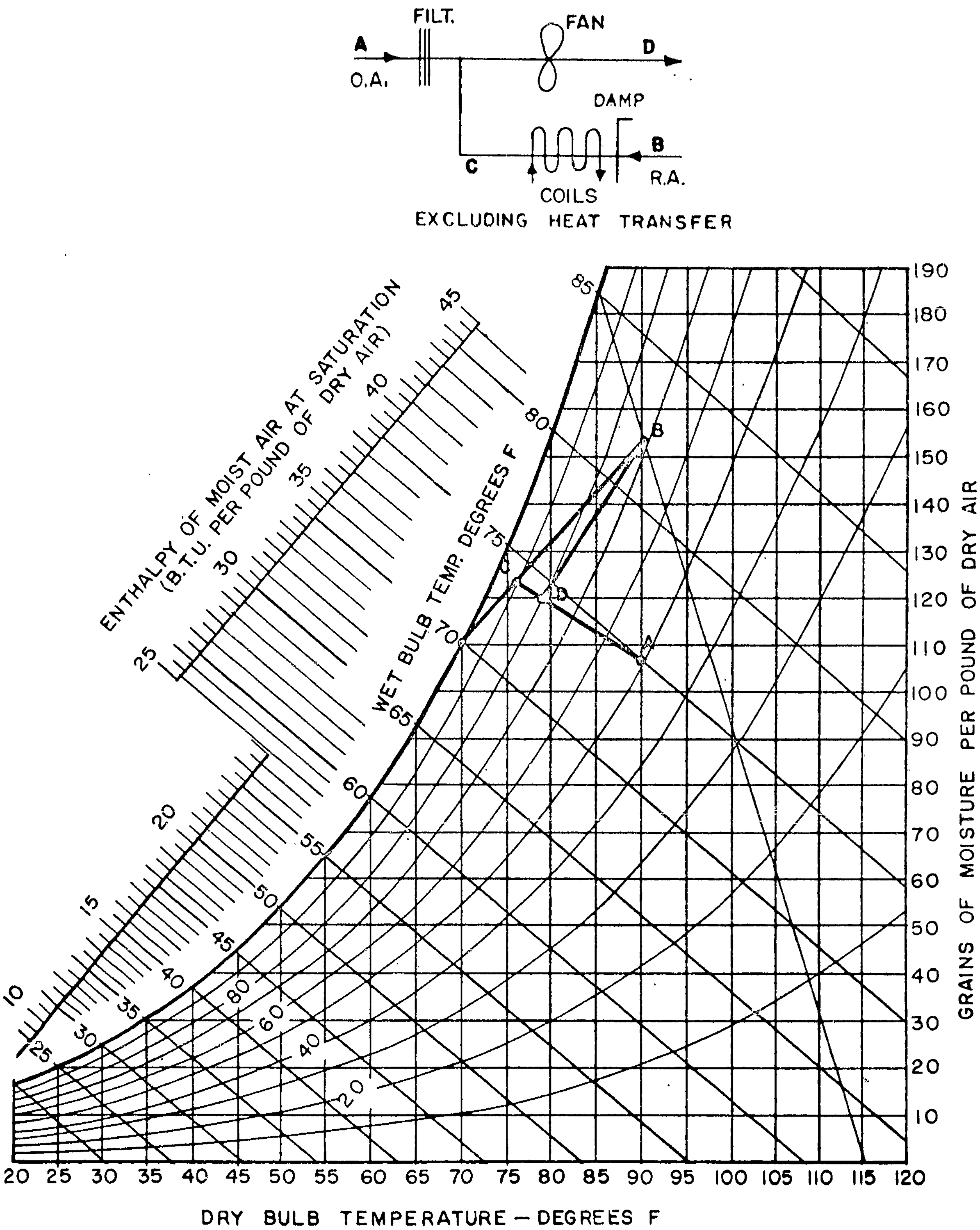
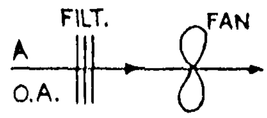

FILT.
FAN
A
O.A.
D
DAMP
B
C
R.A.
COILS
EXCLUDING HEAT TRANSFER
ENTHALPY OF MOIST AIR AT SATURATION
(B.T.U. PER POUND OF DRY AIR)
WET BULB TEMP. DEGREES F
GRAINS OF MOISTURE PER POUND OF DRY AIR
DRY BULB TEMPERATURE — DEGREES F

FIG. 6.66



VENTILATION ONLY
INCLUDING HEAT TRANSFER

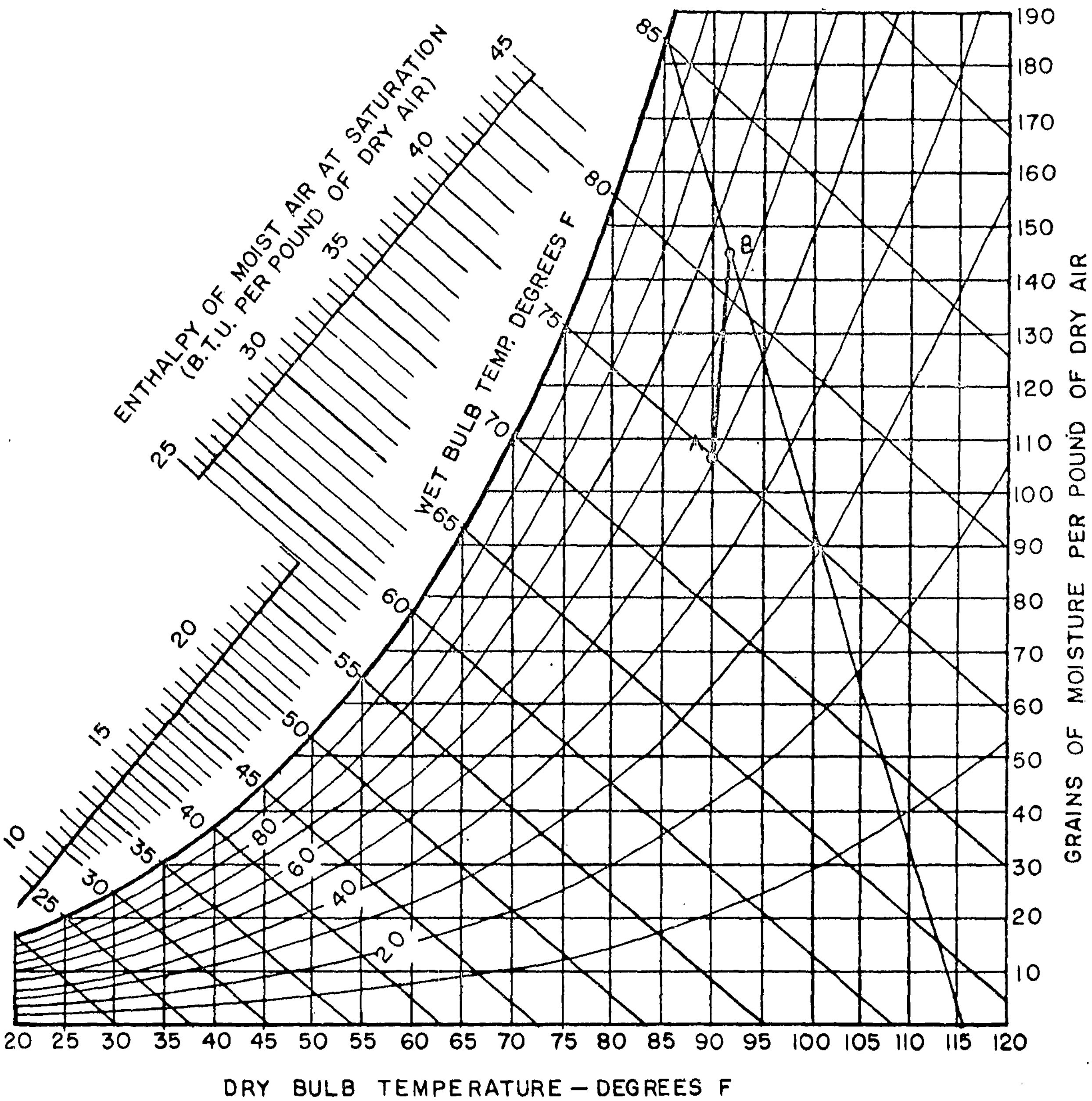


FIG. 6.67

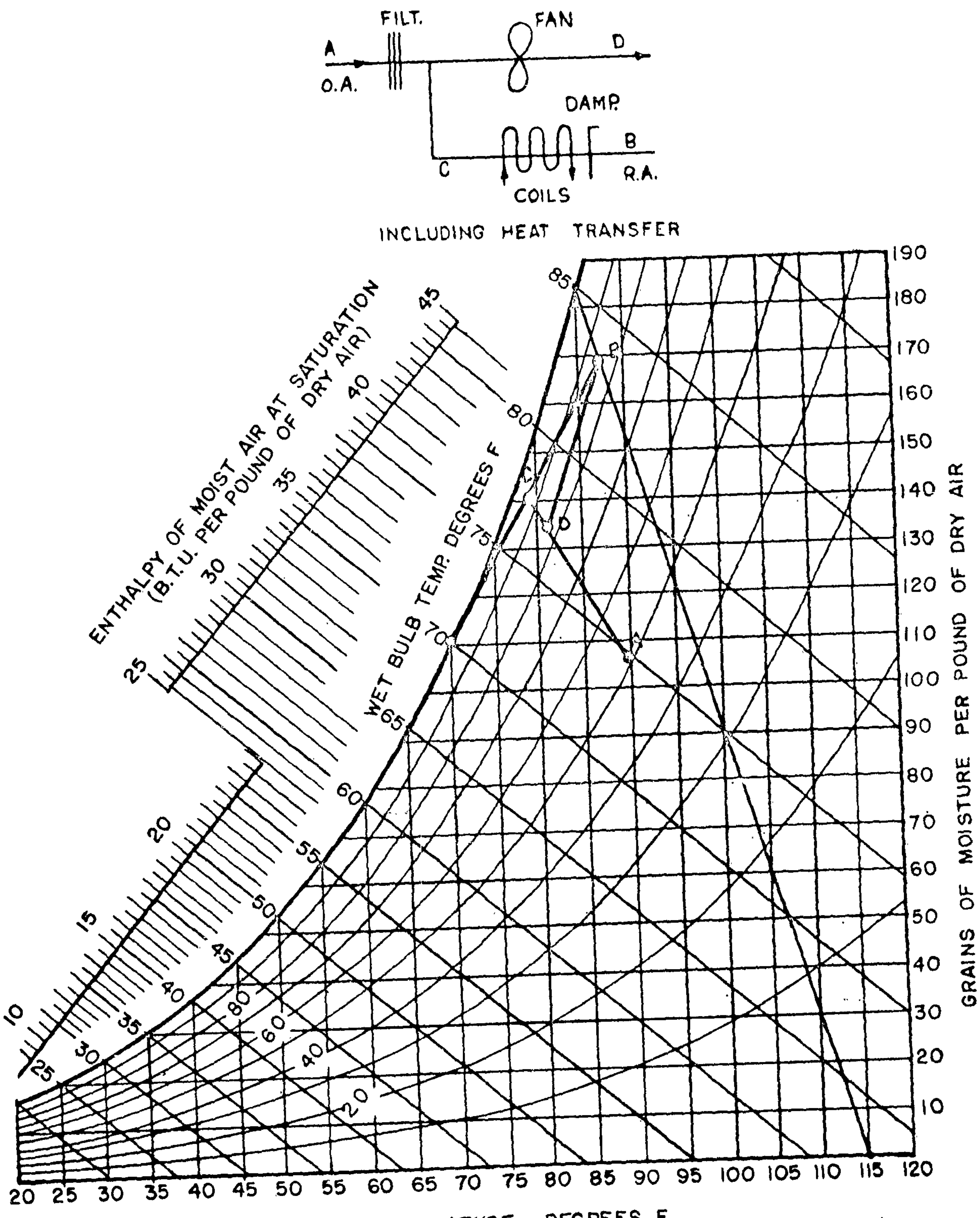
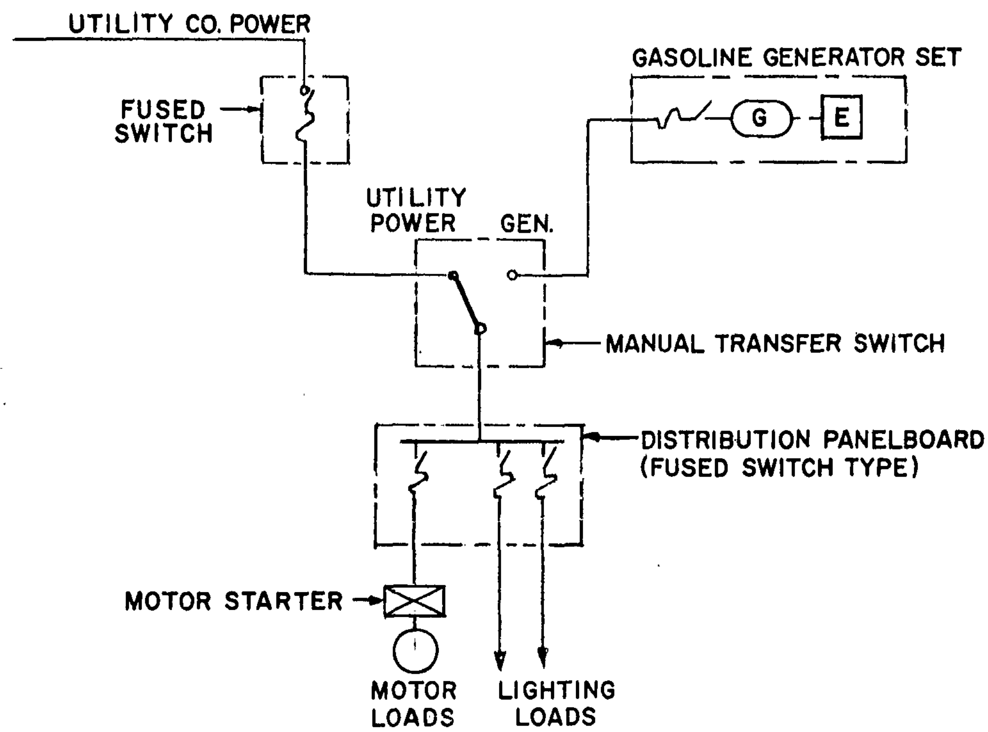

FILT.
FAN
A
O.A.
D
DAMP.
B
R.A.
C
COILS
INCLUDING HEAT TRANSFER
ENTHALPY OF MOIST AIR AT SATURATION
(B.T.U. PER POUND OF DRY AIR)
WET BULB TEMP. DEGREES F
GRAINS OF MOISTURE PER POUND OF DRY AIR
DRY BULB TEMPERATURE — DEGREES F

FIG.6.68



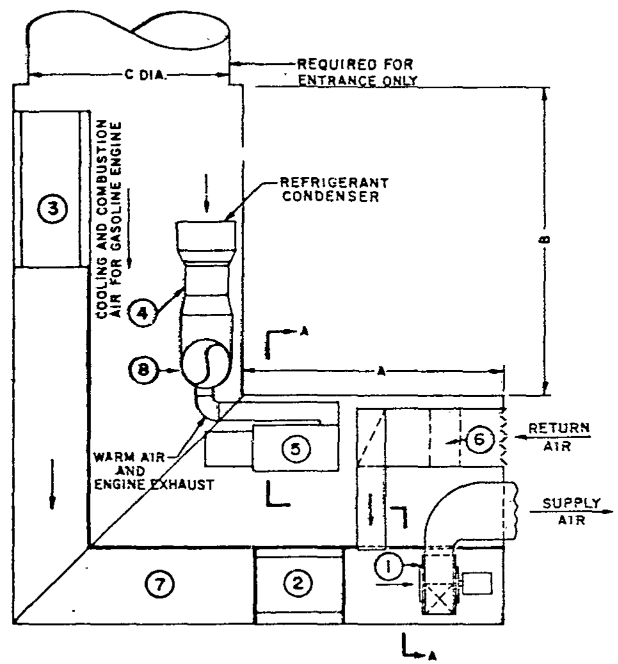
TYPICAL ELECTRICAL DISTRIBUTION SYSTEM

FIG. 6.69

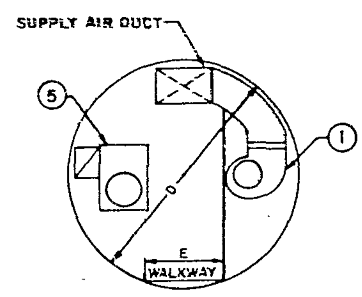
DIM.	CAPACITY (PERSONS)		
	100	250	500
A	9'-0"	10'-0"	11'-0"
B	11'-0"	11'-6"	13'-0"
C	7'-0"	7'-0"	8'-0"
D	8'-0"	9'-0"	12'-0"
E	2'-8"	2'-8"	4'-0"

LEGEND

1-FAN
2-REFRIGERANT COMPRESSOR OR WELL WATER PUMP
3-CBR FILTER
4-COOLING AIR FAN
5-GASOLINE ENGINE GENERATOR
6-WATER OR DX COOLING COIL
7-FILTERED AIR DUCT
8-EXHAUST TO ATMOSPHERE



PLAN



SECTION A-A

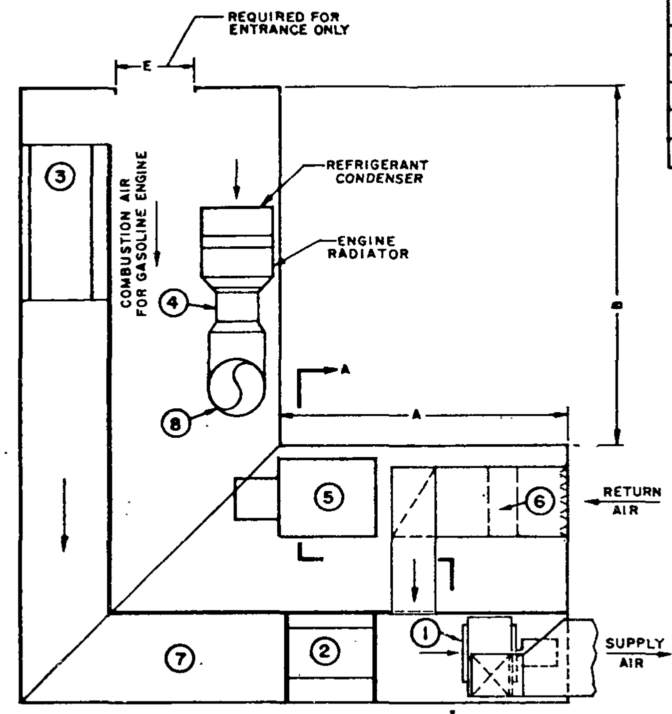
ENTRANCE PACKAGE UNITS
MECHANICAL EQUIPMENT LAYOUT
CIRCULAR SECTION

FIG. 6.70

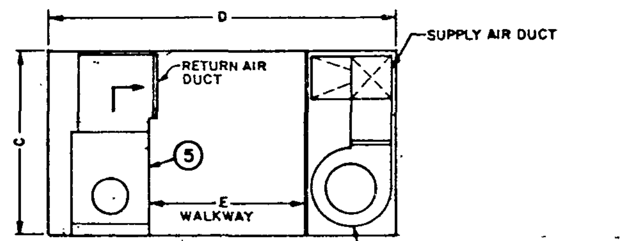
DIM.	CAPACITY (PERSONS)		
	100	250	500
A	9'-0"	10'-0"	11'-0"
B	12'-0"	12'-6"	14'-0"
C	6'-6"	6'-6"	6'-6"
D	8'-0"	9'-0"	12'-0"
E	2'-8"	2'-8"	4'-0"

L E G E N D

1-FAN
2-REFRIGERENT COMPRESSOR OR WELL WATER PUMP
3-CBR FILTER
4-COOLING AIR FAN
5-GASOLINE ENGINE GENERATOR
6-WATER OR DX COOLING COIL
7-FILTERED AIR DUCT
8-EXHAUST TO ATMOSPHERE



PLAN



SECTION A-A

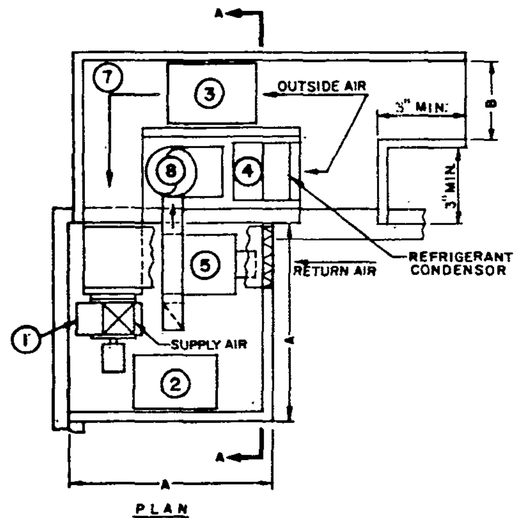
ENTRANCE PACKAGE UNITS
MECHANICAL EQUIPMENT LAYOUT
RECTANGULAR SECTION

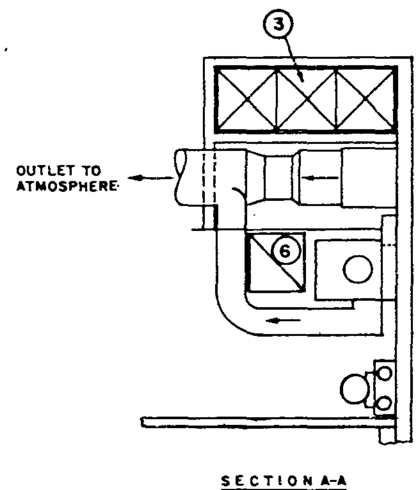
FIG. 6.71

DIM.	CAPACITY (PERSONS)		
	100	500	1000
A	7'-0"	8'-0"	9'-0"
B	2'-8"	2'-8"	4'-0"

LEGEND

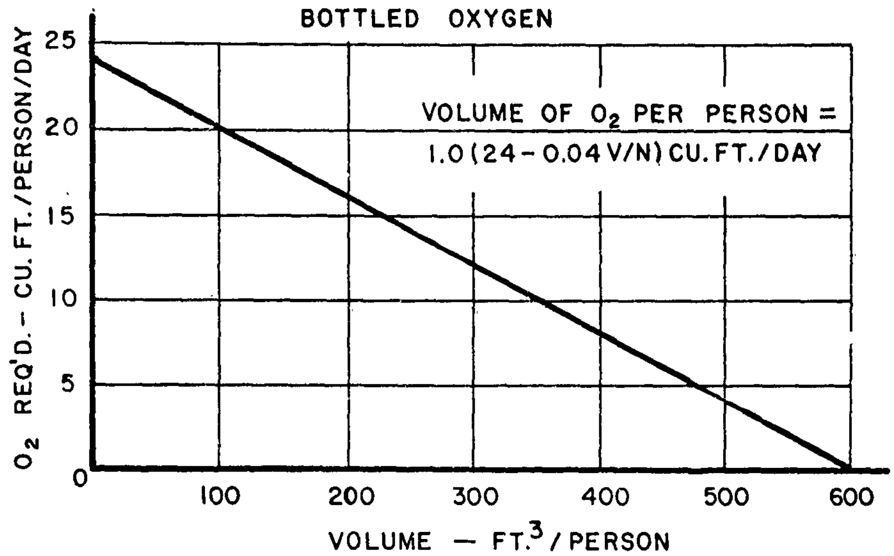
1—FAN
2—REFRIGERANT COMPRESSOR OR WELL WATER PUMP
3—CBR FILTER
4—COOLING AIR FAN
5—GASOLINE ENGINE GENERATOR
6—WATER OR DX COOLING COIL
7—FILTERED AIR DUCT
8—EXHAUST TO ATMOSPHERE





INTERIOR PACKAGE UNITS
MECHANICAL EQUIPMENT LAYOUT

FIG. 6.72


BOTTLED OXYGEN
VOLUME OF O_2 PER PERSON =
1.0(24 - 0.04 V/N) CU. FT./DAY
O_2 REQ'D. - CU. FT./PERSON/DAY
0
5
10
15
20
25
100
200
300
400
500
600
VOLUME — FT.^{3}/PERSON

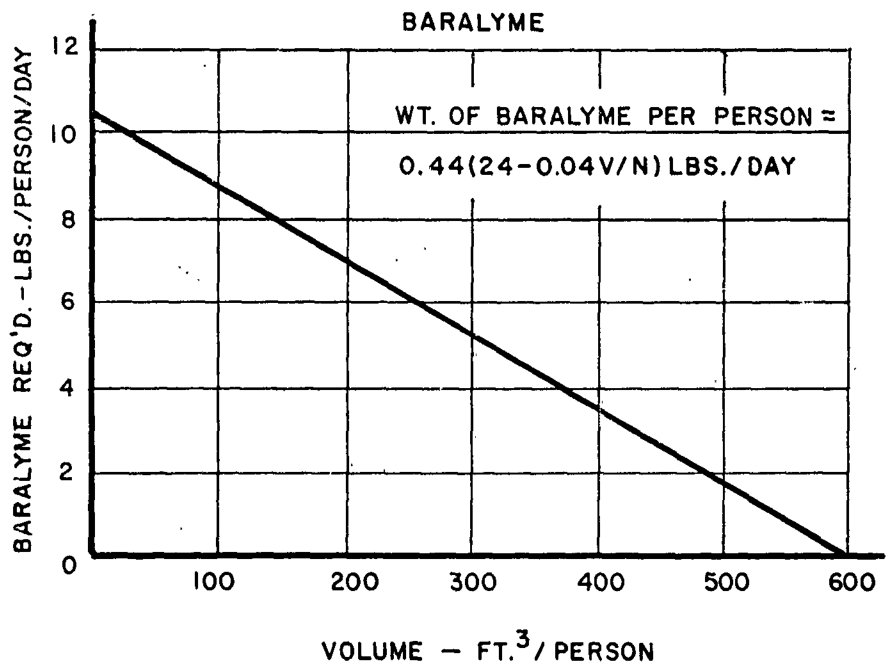

BARALYME
WT. OF BARALYME PER PERSON =
0.44(24-0.04V/N) LBS./DAY
BARALYME REQ'D.-LBS./PERSON/DAY
0
2
4
6
8
10
12
100
200
300
400
500
600
VOLUME — FT.^{3}/PERSON

FIG. 6.73

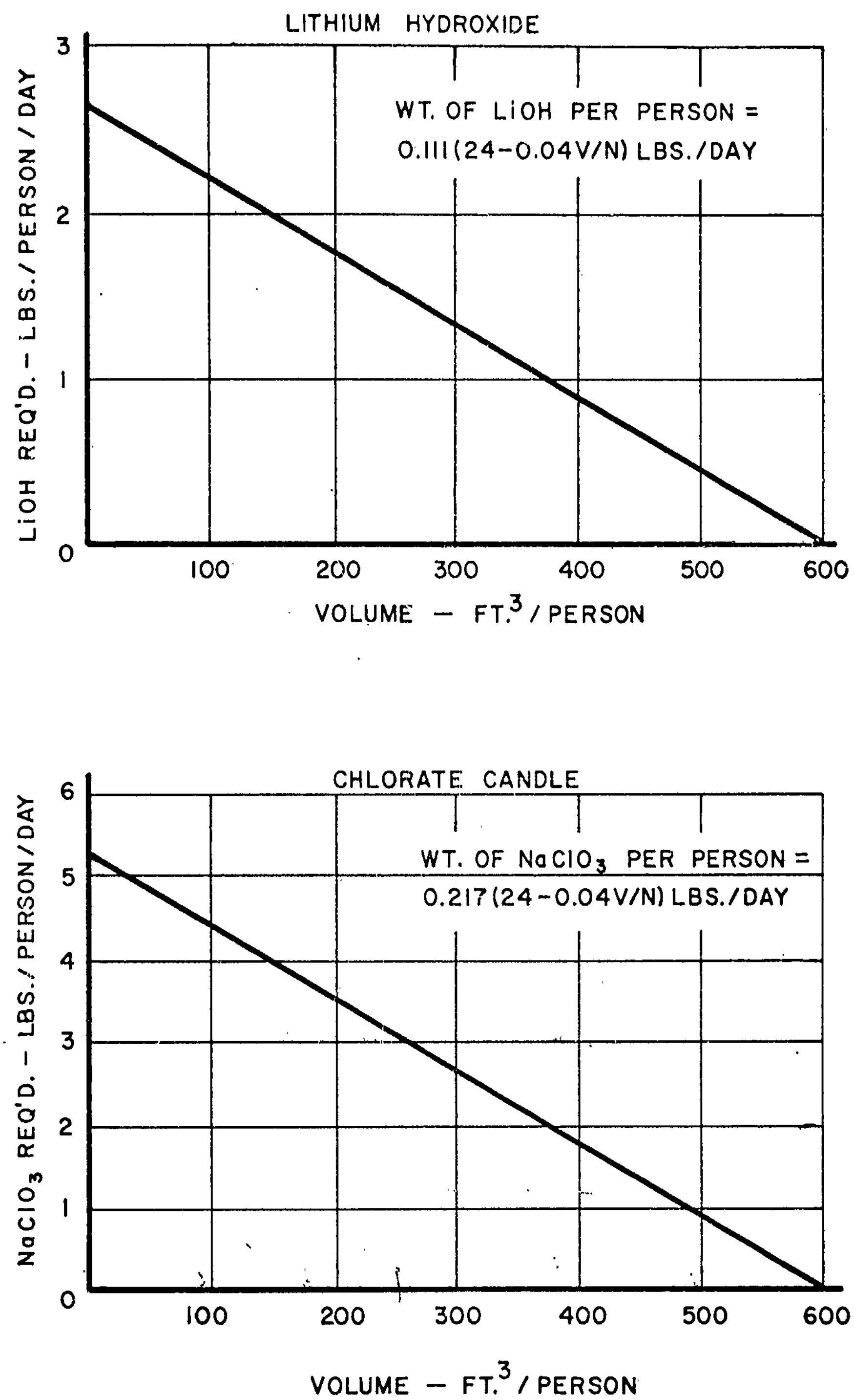

LITHIUM HYDROXIDE
WT. OF LiOH PER PERSON =
0.111 (24-0.04V/N) LBS./DAY
LiOH REQ'D. - LBS./PERSON/DAY
VOLUME — FT.3 / PERSON
CHLORATE CANDLE
WT. OF NaClO3 PER PERSON =
0.217 (24-0.04V/N) LBS./DAY
NaClO3 REQ'D. - LBS./PERSON/DAY
VOLUME — FT.3 / PERSON

FIG. 6.74

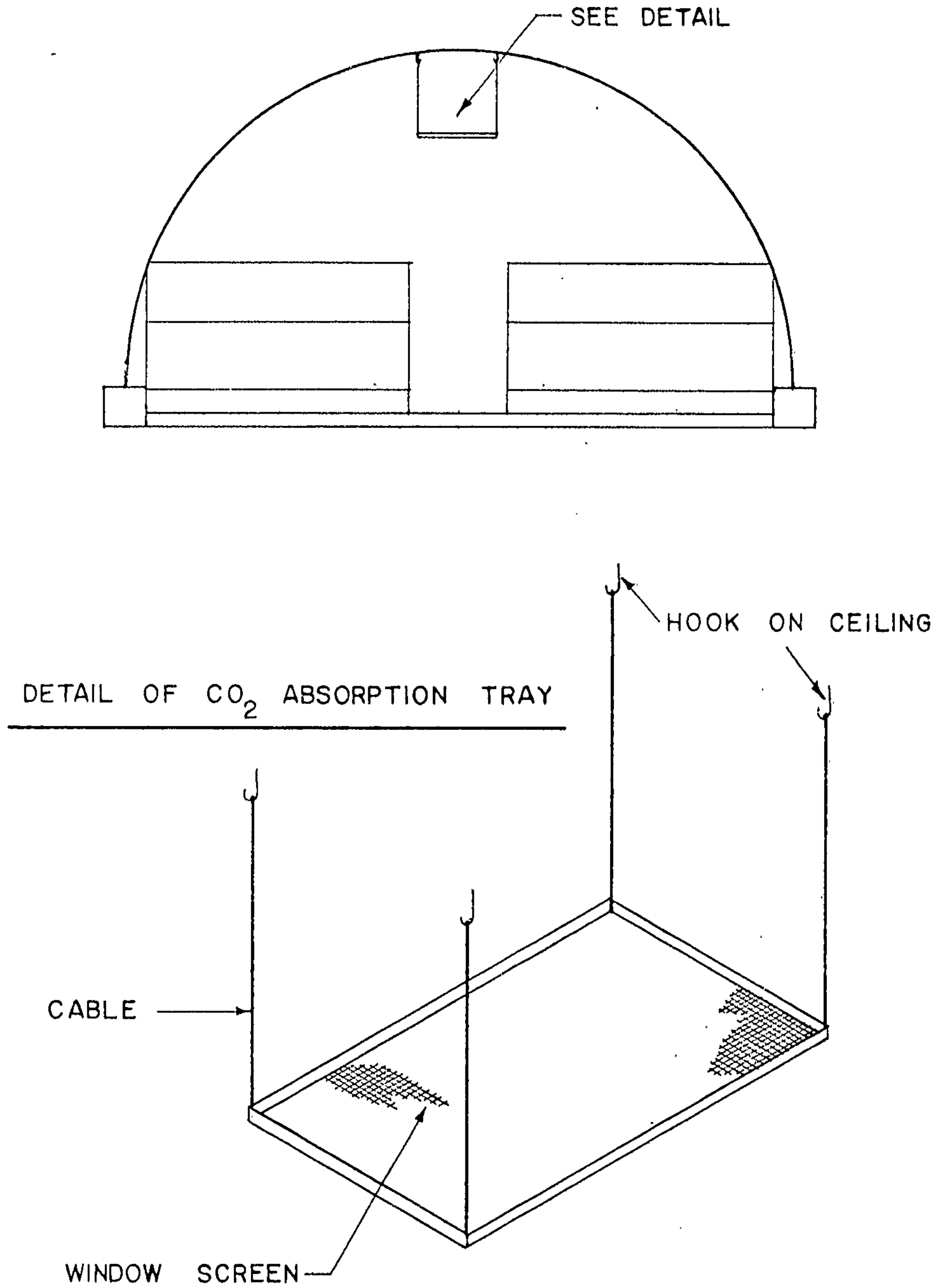
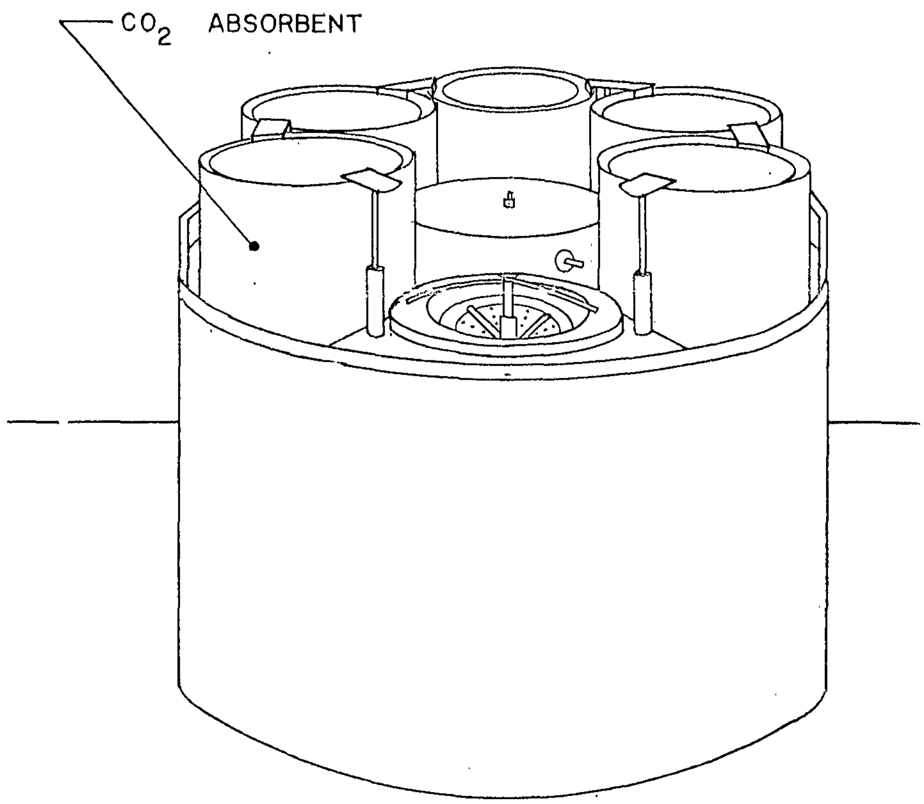
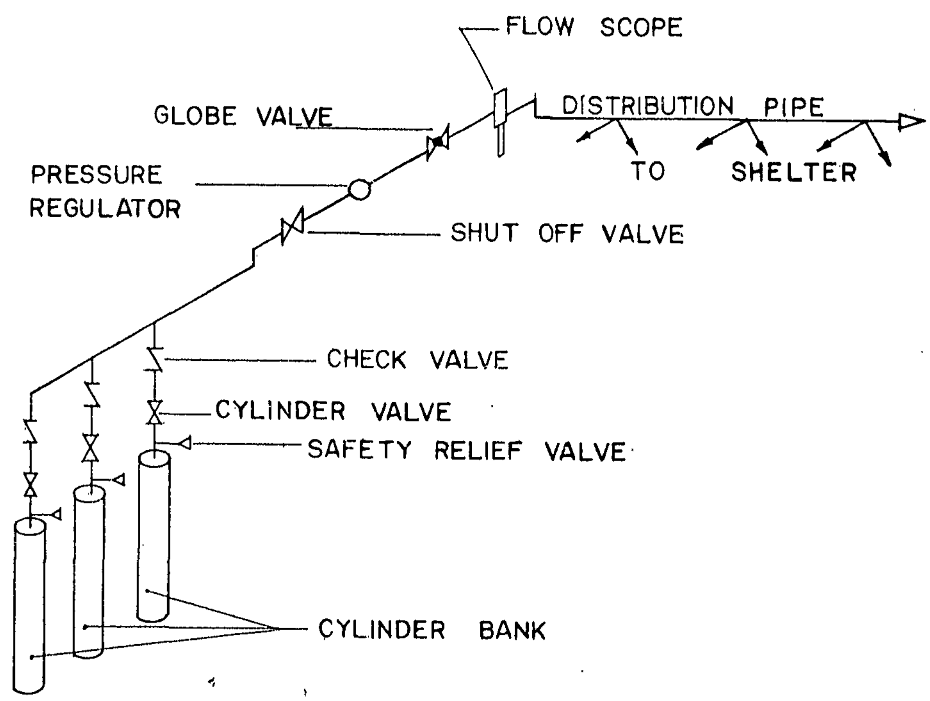

SEE DETAIL
HOOK ON CEILING
DETAIL OF CO_2 ABSORPTION TRAY
CABLE
WINDOW SCREEN

FIG. 6.75



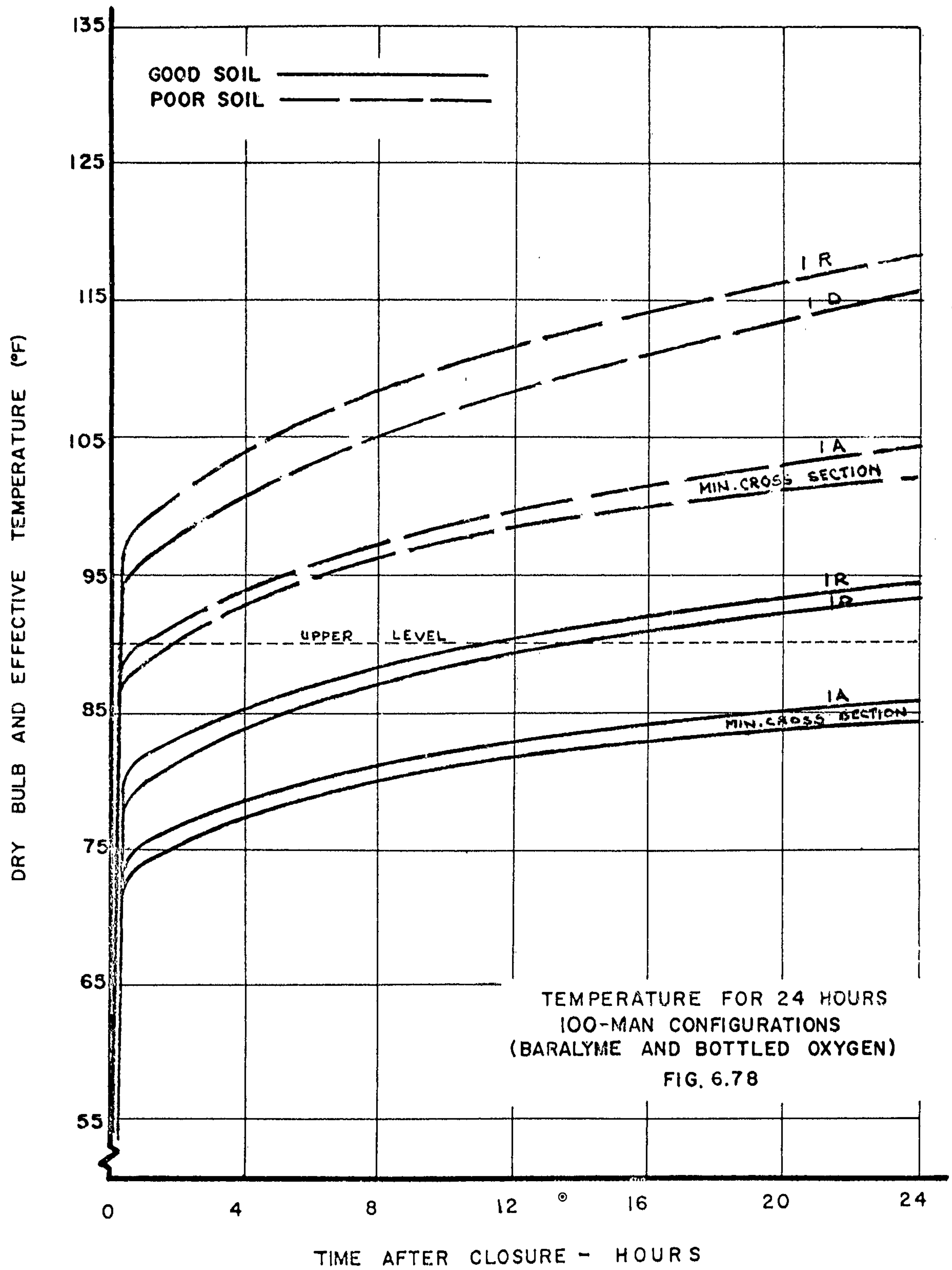
CO_2 ABSORBENT CANNISTER RECEPTACLE [6]

FIG. 6.76

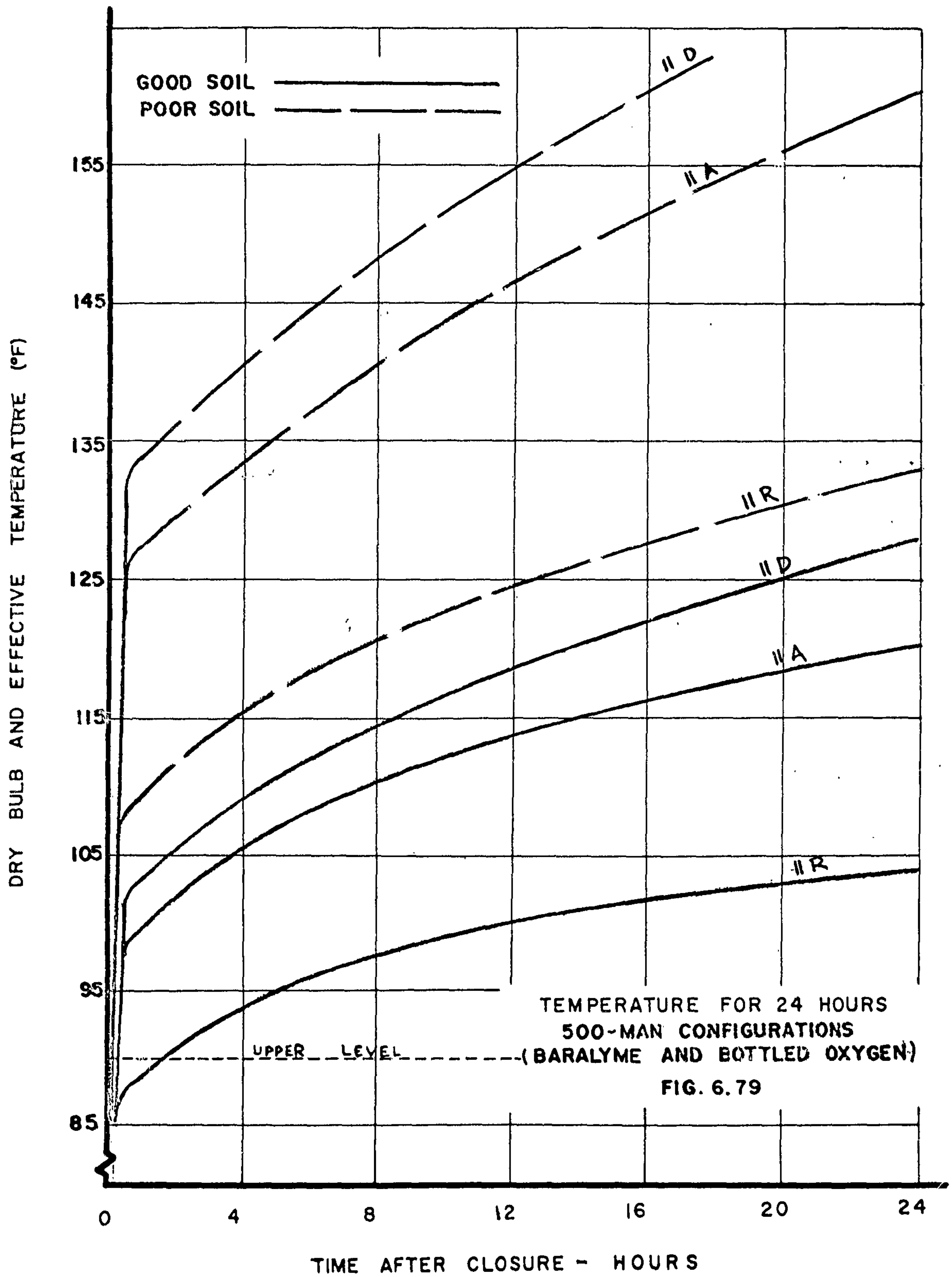


TYPICAL OXYGEN SUPPLY SYSTEM

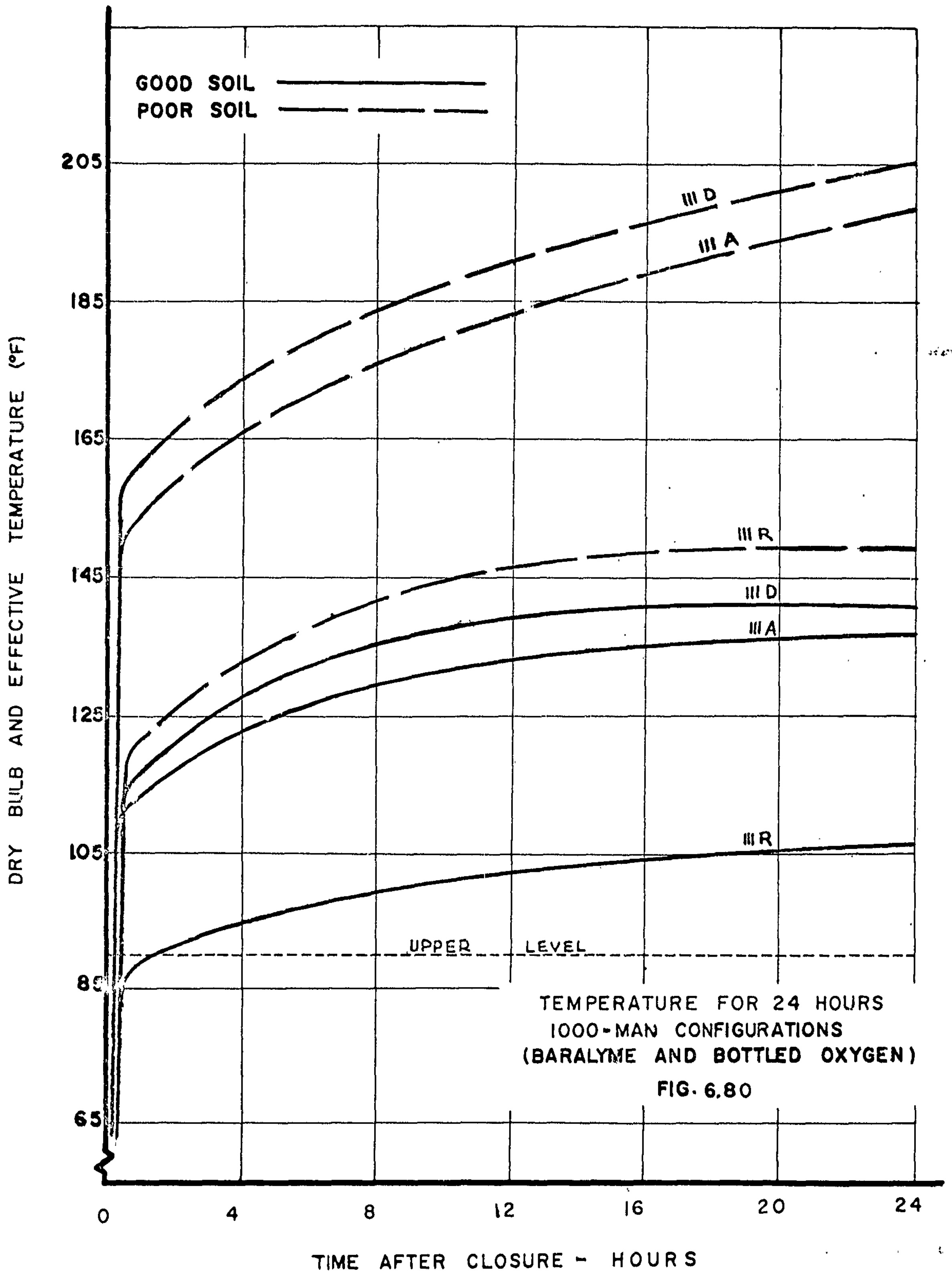
FIG. 6. 77



TEMPERATURE FOR 24 HOURS
100-MAN CONFIGURATIONS
(BARALYME AND BOTTLED OXYGEN)
FIG. 6.78



TEMPERATURE FOR 24 HOURS
500-MAN CONFIGURATIONS
(BARALYME AND BOTTLED OXYGEN)
FIG. 6.79



TEMPERATURE FOR 24 HOURS
1000-MAN CONFIGURATIONS
(BARALYME AND BOTTLED OXYGEN)
FIG. 6.80

SECTION 7

CONCLUSIONS

7.1 OPTIMUM CONFIGURATIONS

From the results of the various component analyses, it is now possible to establish optimum physical sizes for rectangular, arch and dome structures for each selected capacity. Typical arrangements for these are shown on Figures 7.1 through 7.9. Space allotments are given in Table 7.1, 7.2 and 7.3.

7.2 COST INFORMATION

Cost data for each of the above structures are given in Table 7.4 along with other pertainent data. Costs are for the basic structure plus entrance (s) and exit (s) as required. The reader is cautioned that the figures do not include overhead, profit, contingencies and other miscellaneous contractural expenses.

7.3 DISCUSSION OF RESULTS

There are several interesting results which can be drawn from the above information and from other sections of the study. For purposes of clarity, these will be discussed individually.

7.3.1 SHAPE AND STRUCTURAL COST

Within the range of capacities and overpressures selected for study there does not appear to be a single shape emerging as optimum from a cost standpoint. Among the various combinations studied, nearly square rectangular structures are favored as fallout shelters and (but less clearly) as large-capacity 35 psi shelters. Beyond this, concrete and/or steel arch structures may prove competitive. Overall, the reinforced concrete dome seems a less likely choice across our entire spectrum of criteria.

(text continued on page 181)

TABLE 7.1

RECTANGULAR STRUCTURES

Summary of Areas

Size	CAPACITY 100 25'-4"x32'-0"	500 63'-4"x62'-0"	1000 88'-8"x84'-0"
Bunks & Access Aisles	5.00	5.00	5.00
Main Aisles	1.01	1.01	0.74
Toilets & Access Aisles	0.90	0.90	0.90
Administration	0.50	0.50	0.50
Mech-Elect.	0.49	0.26	0.16
Storage	0.13	0.13	0.13
Misc. Unacc. Spaces	.07	.10	.07
TOTAL	8.1 Sq.Ft.	7.9 Sq. Ft. PER PERSON	7.5 Sq. Ft.

TABLE 7.2

ARCH STRUCTURES

Summary of Areas

	CAPACITY		
	100	500	1000
Size	16'Dia x 67'-8"Lg	35'Dia. x 80'-2"Lg	49'Dia x 76'-0"Lg
Bunks & Access Aisles	7.29*	5.41	5.34
Main Aisles & Stairways	.31*	1.50	1.08
Toilets & Access Aisles	1.28	.98	.95
Administration	.50	.50	.50
Mech-Elect.	.49	.26	.16
Storage	.13	.13	.13
Misc. Unacc. Spaces	-	.22	.24
	10.00 Sq.Ft.	9.00 Sq.Ft. PER PERSON	8.40 Sq.Ft.

*Note: For the 16' Diameter Arch, bunk access is from the main aisles.

TABLE 7.3

DOME STRUCTURES

Summary of Areas

Size	CAPACITY 100 35' Dia.	500 55' Dia.	1000 66' Dia.
Bunks, Seats and Access Aisles	5.40	5.50	5.46
Main Aisles & Stairways	1.36	1.00	.94
Toilets & Access Aisles	.81	.95	.93
Administration	.50	.50	.50
Mech-Elect.	.63	.31	.19
Storage	.13	.13	.13
Misc. Unacc. Spaces	.27	.21	.25
	9.1 Sq. Ft.	8.6 Sq. Ft. PER PERSON	8.4 Sq. Ft.

TABLE 7.4

BASIC COST AND PHYSICAL DATA

(PER PERSON BASIS)

Config.	Mat'l	Size	Floor Area	Vol.	Surf. Area	Cost - Dollars Per Person								
						35 psi			60 psi			Nominal		
			Ft^2	Ft^3	Ft^2	Shltr	Ent.	Tot.	Shltr	Ent.	Tot.	Shltr	Ent.	Tot.
100-PERSON SHELTER														
Rect.	Conc.	25'-4"x32'-0"	8.1	59	24.6	79	27	106	115	33	148	53	22	75
Arch	Conc.	16'D.x67'-8"	10.0	68	29.3	71	27	98	77	33	110	71	22	93
Arch	Steel	16'D.x67'-8"	10.0	68	29.3	81	27	108	95	32	127	76	22	98
Dome	Conc.	35' Diameter	9.1	112	28.8	95	38	133	135	45	180	95	32	127
500-PERSON SHELTER														
Rect.	Conc.	63'-4"x62'-0"	7.9	58	19.4	54	8	62	86	9	95	33	6	39
Arch	Conc.	35'D.x80'-2"	9.0	77	16.4	68	12	80	77	13	90	68	10	78
Arch	Steel	35'D.x80'-2"	9.0	77	16.4	62	12	74	74	14	88	61	11	72
Dome	Conc.	55' Diameter	8.6	87	14.1	56	18	74	92	20	112	56	16	72
1,000-PERSON SHELTER														
Rect.	Conc.	88'-8"x84'-0"	7.5	55	17.5	47	4	51	76	5	81	31	4	35
Arch	Conc.	49'D.x76'-0"	8.4	72	11.5	65	9	74	74	11	85	65	8	73
Arch	Steel	49'D.x76'-0"	8.4	72	11.5	59	10	69	77	12	89	58	10	68
Dome	Conc.	66' Diameter	8.4	73	10.3	52	11	63	77	13	90	52	11	63

(Costs Do Not Include Overhead, Profit or Contingencies)

7.3.2 SIZE AND STRUCTURAL COST

Perhaps the most significant result we find concerns the cost difference between large and small shelters. On a per-capita basis, 1000-person units appear to be roughly half the cost of 100-person units whether designed for blast or fallout protection. This order-of-magnitude saving appears to occur somewhat below 1000 capacity as indicated by the basic costs for the 500-person units. Extrapolating the data given in Table 7.4 to 5000-person units, we can infer that the following cost savings over 1000-person units may be possible: For fallout shelters and 60 psi blast shelters, 5-15%; for 35 psi blast shelters, 15-25%. Of course, it would be necessary to do the design and cost analyses of the 5000-person units in order to verify these figures.

7.3.3 BLAST PROTECTION AND STRUCTURAL COST

For steel and concrete arches and concrete domes, minor cost increases are incurred when going from the nominal live-load design (fallout shelters) to the 35 psi level since, essentially, we would rate the inherent protection of these structures at 35 psi. For the rectangular structures this is not so, since their inherent protection is nearer 5 psi. Additional cost for 35 psi structures over those designed for nominal live-loading varies from 40 to 50% per person depending on capacity.

Considering optimum structures only, designing to 60 psi will result in cost increases (over fallout shelters) of about 45% for small shelters and about 130% for large shelters. On a per-capita basis, it appears that large 60 psi structures cost about 10% more than small fallout shelters.

7.3.4 ENVIRONMENTAL CONTROL COSTS

Although this study was not directly concerned with the selection and evaluation of environmental control systems, sufficient information has been developed to allow some conclusions to be drawn. First, well-water cooled systems are highest in performance, lowest in cost (see Table 7.5) and least sensitive to overpressure criteria. Second, high quality environmental control units for large shelters can be half the per-capita cost of similar units for small shelters.

7.3.5 HEAT TRANSFER EFFECTS

There are two general categories of results from the heat transfer analyses. The first concerns the long-term effects which are reflected in cost reductions of environmental control

TABLE 7.5

EFFECT OF HEAT TRANSFER TO SOIL ON

MECHANICAL-ELECTRICAL PACKAGES COSTS

	AVERAGE* HEAT TRANSFER BTU/HR/PERSON	COST IN DOLLARS/PERSON (Including Blast Closures) Vent-Air Cooling	Well-Water Cooling	Refrig. Cooling
100-PERSON SHELTER	0	110	75	91
Rectangular	128	85	74	81
Arch	184	74	74	79
Dome	165	80	74	80
500-PERSON SHELTER	0	66	46	56
Rectangular	91	57	45	53
Arch	94	57	45	53
Dome	93	57	45	53
1,000-PERSON SHELTER	0	56	32	46
Rectangular	87	46	31	42
Arch	70	48	31	43
Dome	73	48	31	43

*For a "good" soil at 55 F. and a metabolic rate of 500 BTU/HR/PERSON over a 14-day period.

packages. The second concerns closure capabilities.

The first category of results (shown in Table 7.5) indicates that for systems relying on outside air for heat dissipation, significant savings might be realized where soil conditions are favorable. For well-water cooled systems, heat transfer to soil has little effect on cost.

The second category is summarized in Table 7.6. From this data we can say that only small cross-sectional configurations have a chance of maintaining survivable temperatures for closure periods approaching 24 hours. In larger shapes, this capability does not appear possible without other means for the dissipation of metabolic heat. If lesser time periods are acceptable, the rectangular configuration will give maximum performance among large shapes.

7.3.6 SPACE UTILIZATION

For austere shelters it is apparent that bunking and access to bunks largely determine space requirements. Bunking systems which are convertible (to seating) and demountable will allow maximum space utilization. With such systems, maximum performance will be achieved in rectangular structures arranged for 4-high tiering of bunks. Arches and domes require complicated bunking systems for maximum space utilization. That is, bunks which can be tiered from one-to five-high.

In addition, 4-high bunking, convertible to 4-abreast seating, may result in minimum management problems, since its use of space is less sensitive to scheduling changes.

It should also be noted that minimum bay size (6'-4" x 6'-4") was an important factor in reducing the cost of rectangular structures. If such spacings prove undesirable for functional reasons and must be increased substantially, the rectangular structure may or may not prove optimum. And, if small bay sizes are feasible, we would recommend that some additional investigation be undertaken to evaluate all concrete (shear wall) structures and to evaluate column- or wall-hung bunks.

7.4 CONCLUDING STATEMENTS

Within the limitations of this study, the following

TABLE 7.6

CLOSURE PERFORMANCE*

	Time To Reach 3% CO_2 & 17% O_2 (Hours)	Time To Reach 90 F. E.T. (Hours)
100-PERSON SHELTER		
Rectangular	2.4	19
Arch	2.5	24
Dome	4.5	21
500-PERSON SHELTER		
Rectangular	2.3	13
Arch	3.1	6
Dome	3.5	4
1,000-PERSON SHELTER		
Rectangular	2.2	11
Arch	2.9	2
Dome	2.9	1

*For a "good" soil at 55 F. and a metabolic rate of 500 BTU/HR/PERSON and using a Baralyme-Bottled Oxygen environmental control system.

statements can be made:

1 - In the category of fallout shelters, single-level rectangular structures designed to accomodate 4-high tiering of bunks will result in minimum cost regardless of capacity.

2 - In the category of blast shelters, the same statement applies, at least for large shelters at 35 psi. At 60 psi, the optimum structure appears to depend on capacity. For optimum configurations, the provision of high-quality blast protection appears to be a costly process. Although optimum underground structures designed for fallout protection only will have some inherent blast protection, we would make a sharp differentiation between fallout and blast shelters in terms of costs and performance requirements.

3 - In the category of capacity, small (100-person) fallout shelters may result in as much as twice the per capita cost of large (500- or 1000-person) fallout shelters. For blast shelters, this difference is much less.

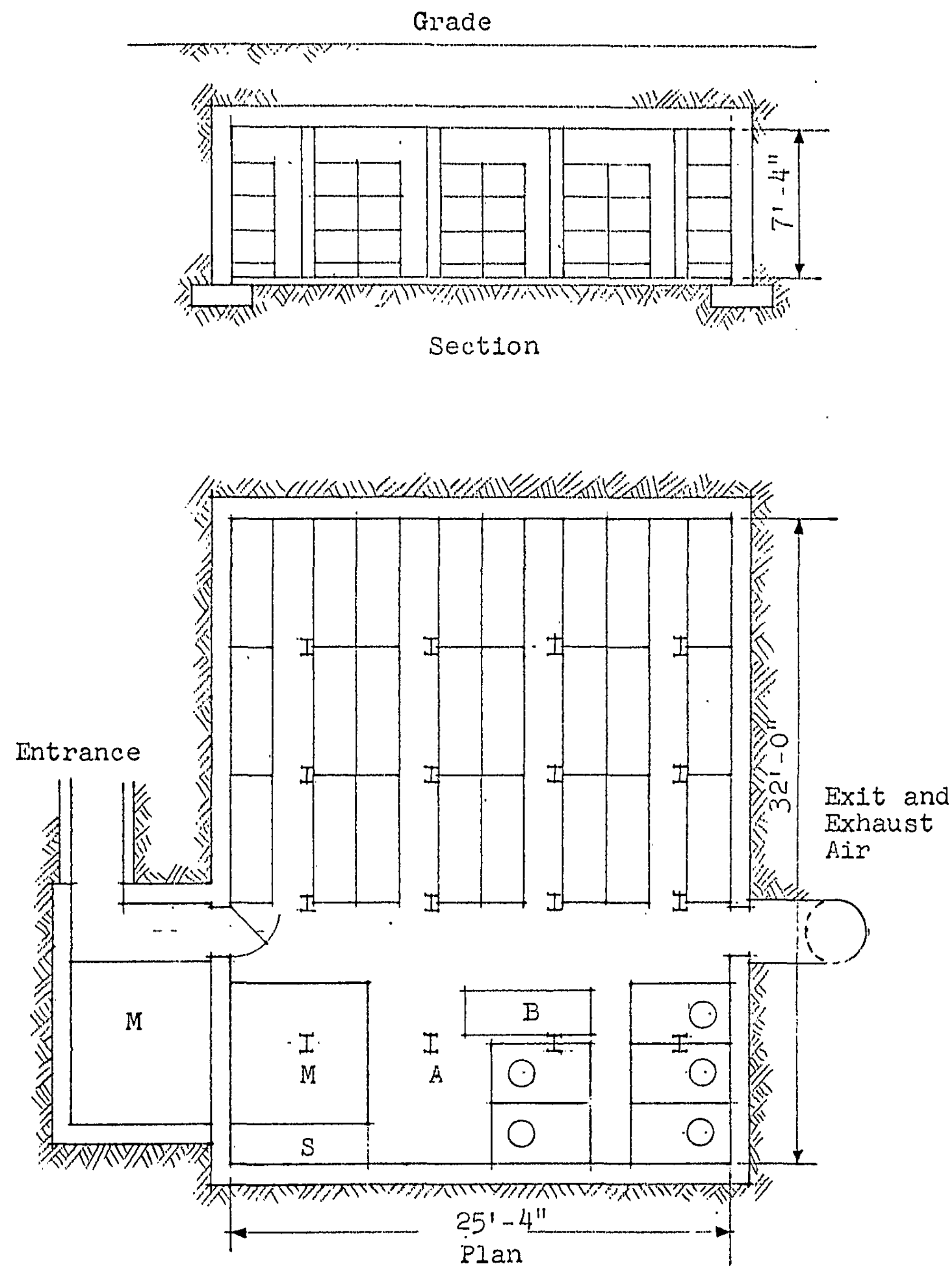
4 - In the category of environmental control, we conclude that high-quality systems are expensive and may cost as much as the optimum shelter structure. Among such systems, those which have an adequate well-water source will be lowest in cost. Heat transfer through the shelter walls will result in nominal cost decreases of mechanical and electrical equipment. Such benefits are highly dependent on ground conditions and construction procedures with the result that they may be marginal for use in planning.

   Also in this category, we conclude that from the cost standpoint, the optimum location for mechanical-electrical equipment is within the shelter proper.

5 - In the category of closure requirements, we conclude that without adequate, protected heat

sinks, shelter configuration and construction procedures may be determined by the heat dissipation criterion. The optimum high quality blast cross-section with a 24-hour closure capability appears to be a minimum diameter concrete arch. This shelter might be arranged in multiple units with common entrances. Also in this category, we conclude that shelter volumes resulting from optimizing shape and space utilization do not have a significant effect on closure capability, either absolutely or between shapes. We also conclude that closure capability can be enhanced through the use of low heat-producing O_2 - CO_2 systems and through shelter management procedures which will keep shelter activity at a minimum level.

6 - In the category of protected entrances, we conclude that a vestibule-type entrance unit will be lowest in cost.



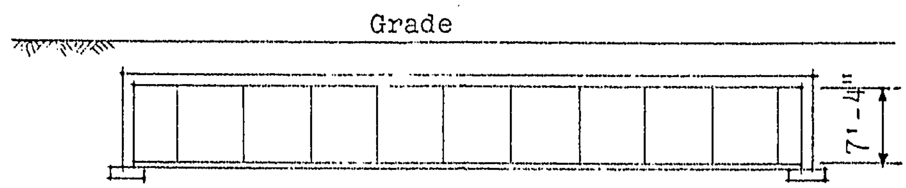
100 MAN SHELTER

Rectangular Structure
(8.1 sq. ft./person)

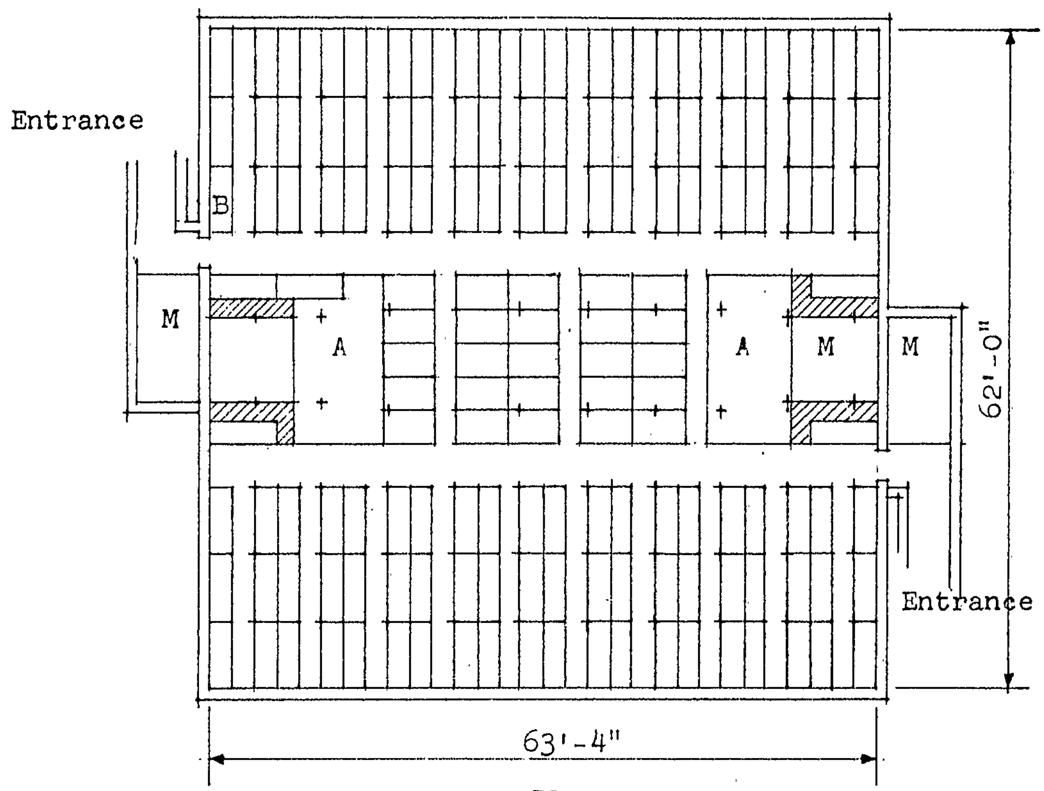
LEGEND

A- Administration
B- Bunks
M- Mechanical
S- Storage

Fig. 7.1



Section



Plan

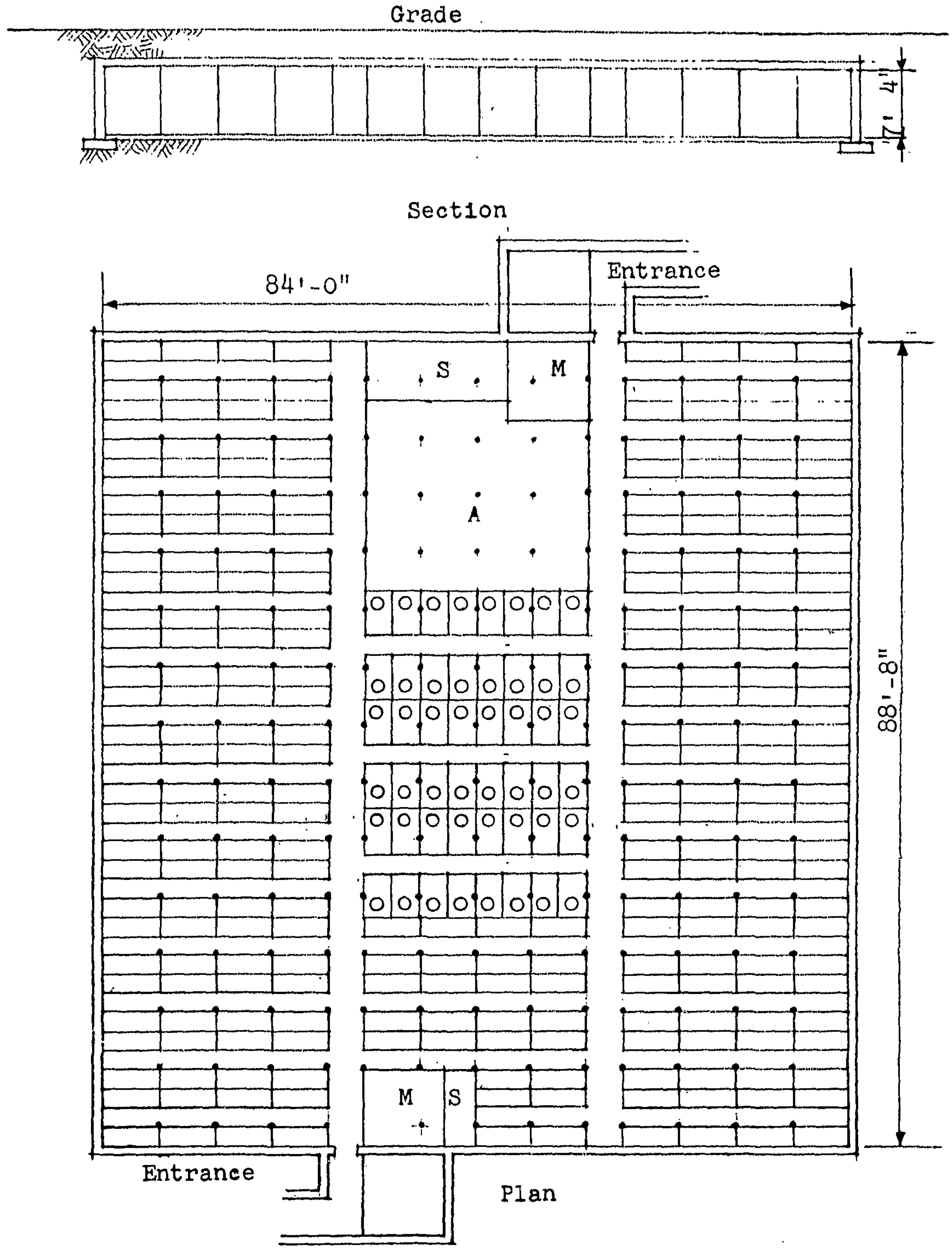
LEGEND

A-Administration
B-Bunks-4 High
M-Mechanics
Storage

500 MAN SHELTER

Rectangular Structure
(7.9 sq. ft./person)

Fig. 7.2



LEGEND

A- Administration
M- Mechanical
S- Storage

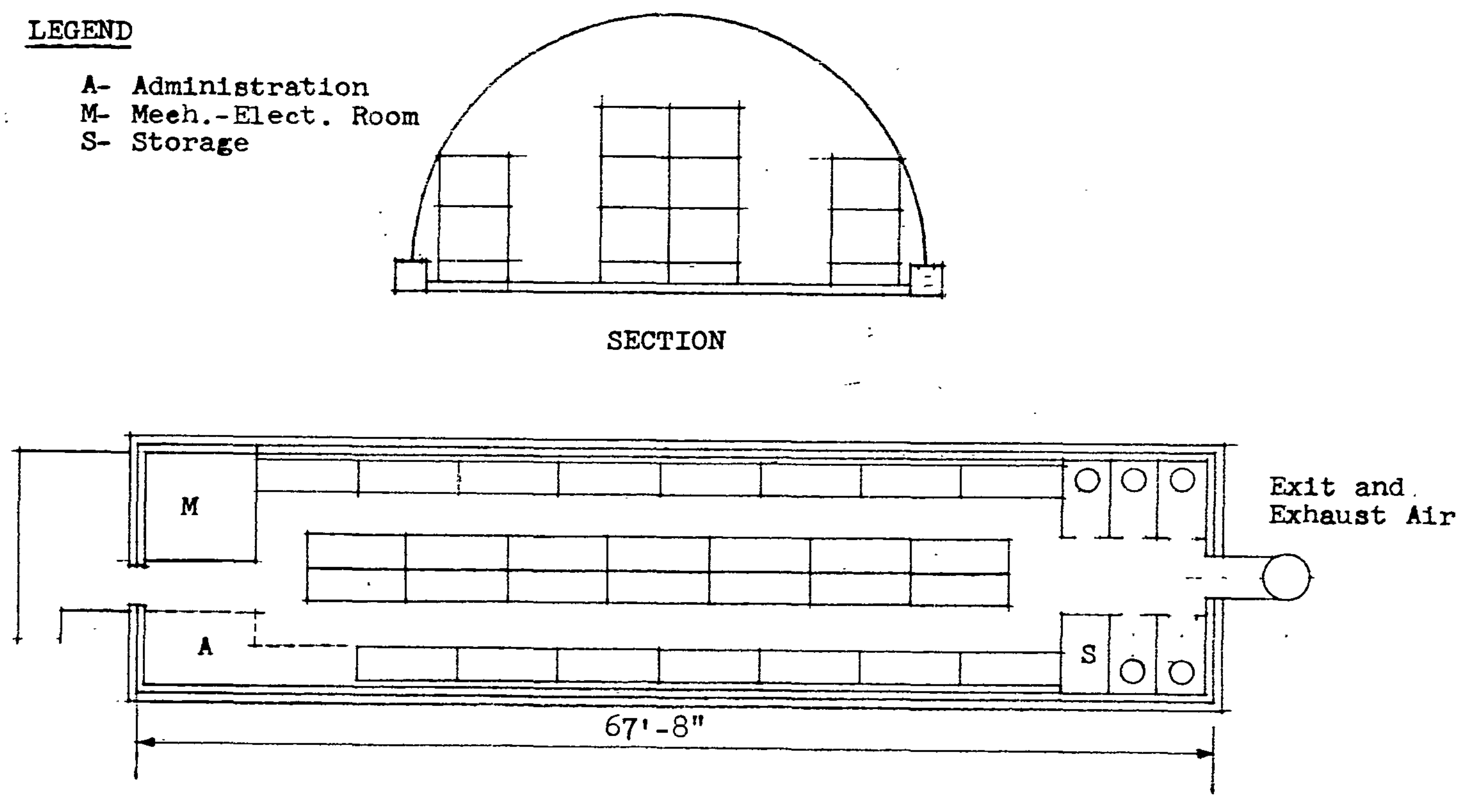
1000 MAN SHELTER

Rectangular Structure
(7.5 sq.ft./person)

Fig.7.3

LEGEND

A- Administration
M- Meeh.-Elect. Room
S- Storage

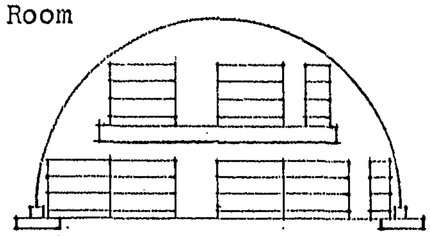


100 MAN SHELTER

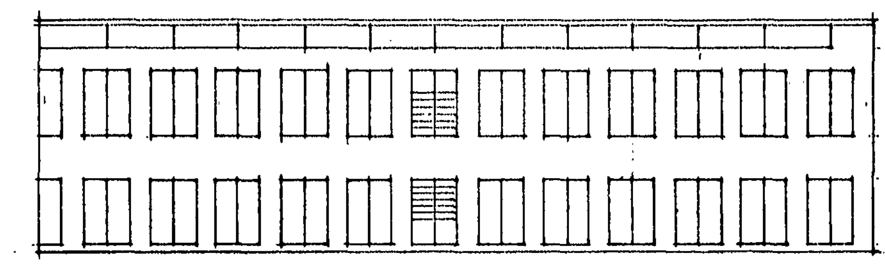
16 Ft. Diameter Areh
(10.0 sq.ft./person)

Fig.7.4

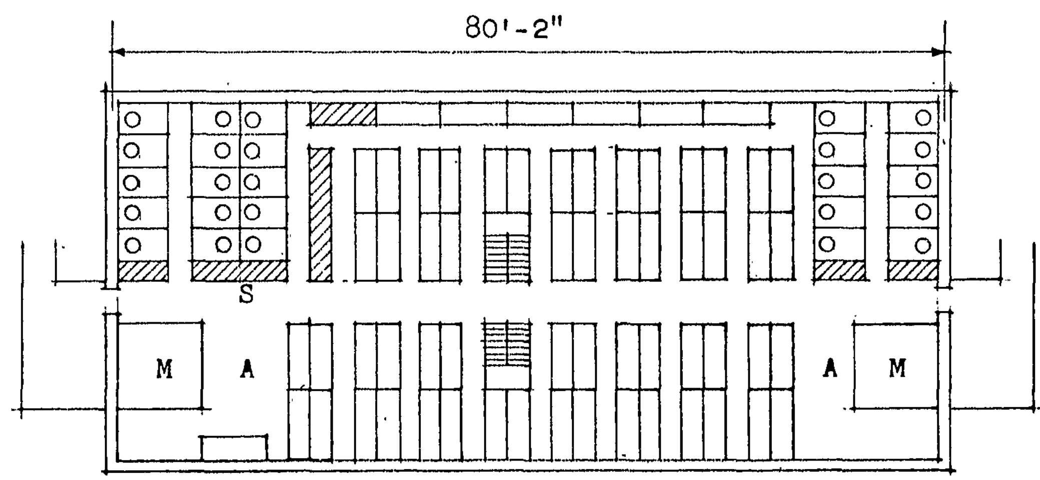
LEGEND
A- Administration
M- Mech.-Elect. Room
S- Storage



SECTION



SECOND FLOOR PLAN

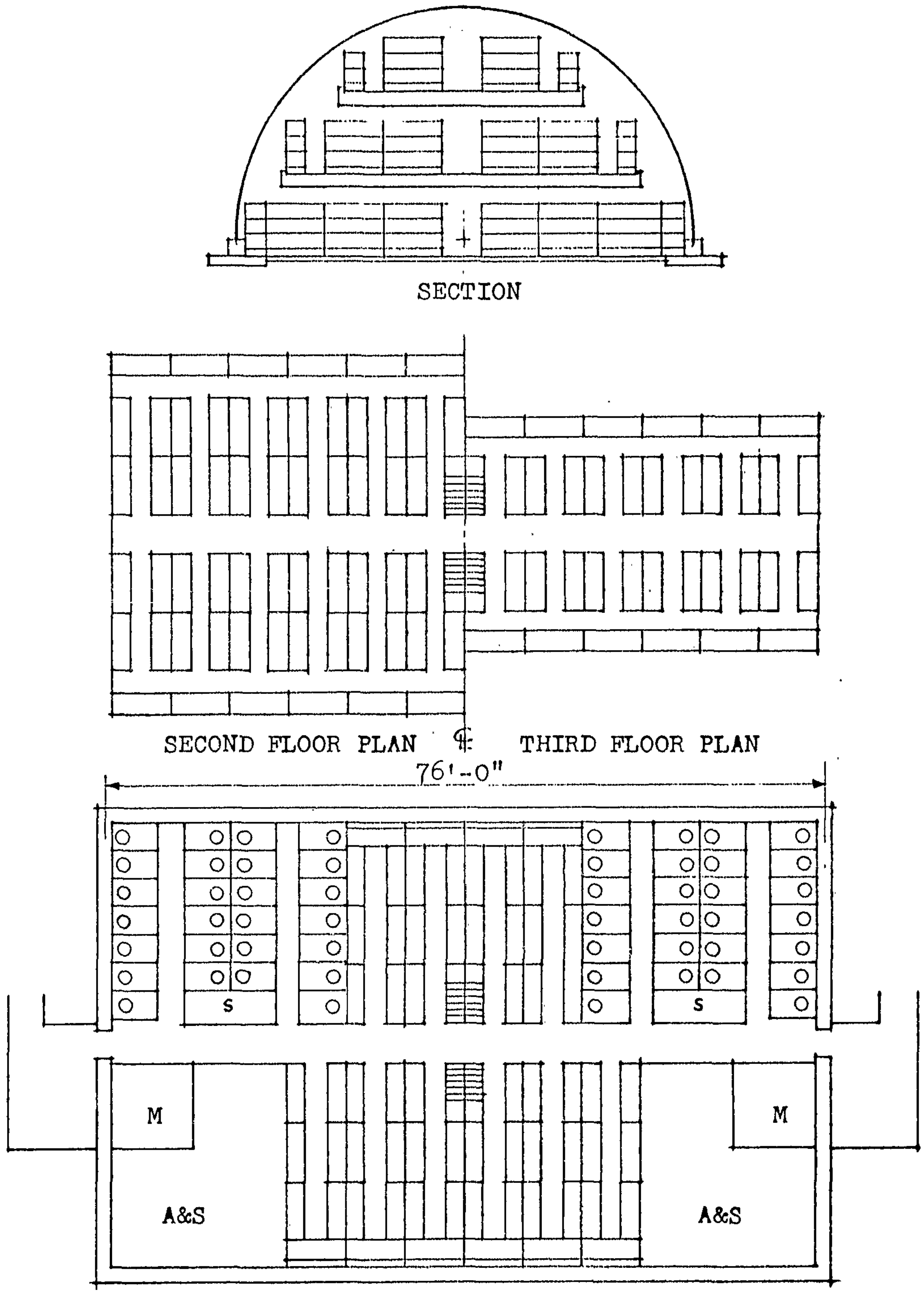


FIRST FLOOR PLAN

500 MAN SHELTER

35 Ft. Diameter Arch
(9.0 sq.ft./person)

Fig.7.5



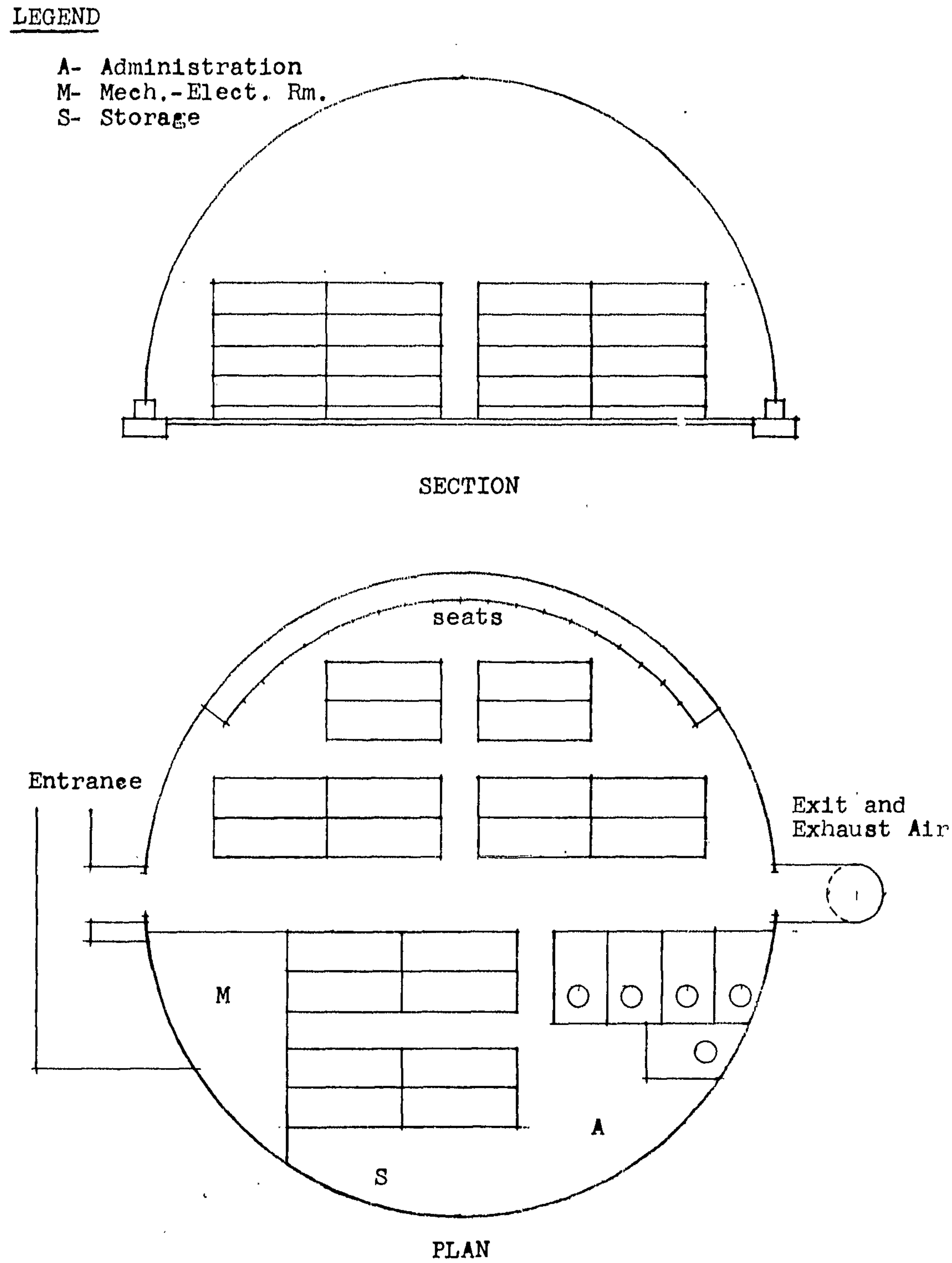
LEGEND

- A- Administration
- M- Mech.-Elect. Room
- S- Storage

1000 MAN SHELTER

49 Ft. Dia. Arch (8.4 sq.ft./ person)

Fig. 7.6



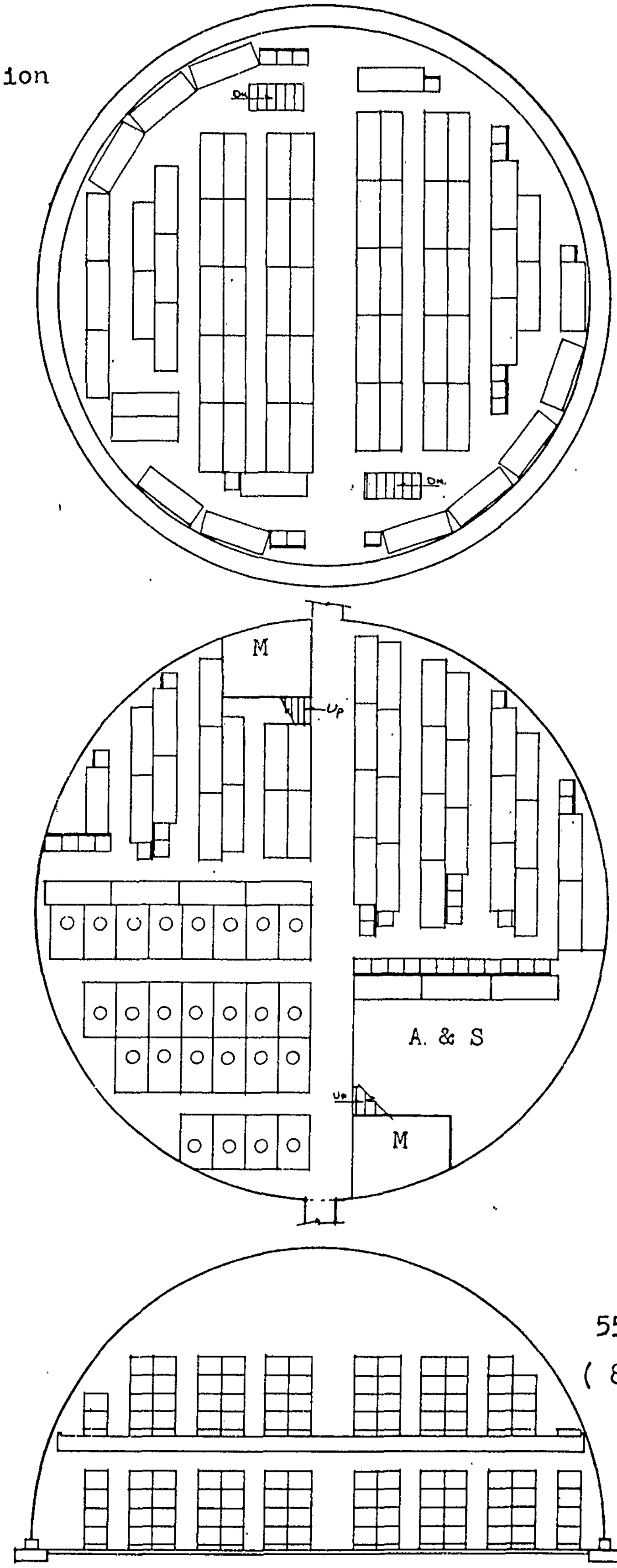
100 MAN SHELTER

35 Ft. Diameter Dome
(9.1 sq.ft./person)

Fig. 7.7

LEGEND

A-Administration
M- Mechanical
S- Storage



First Floor Plan

Second Floor Plan

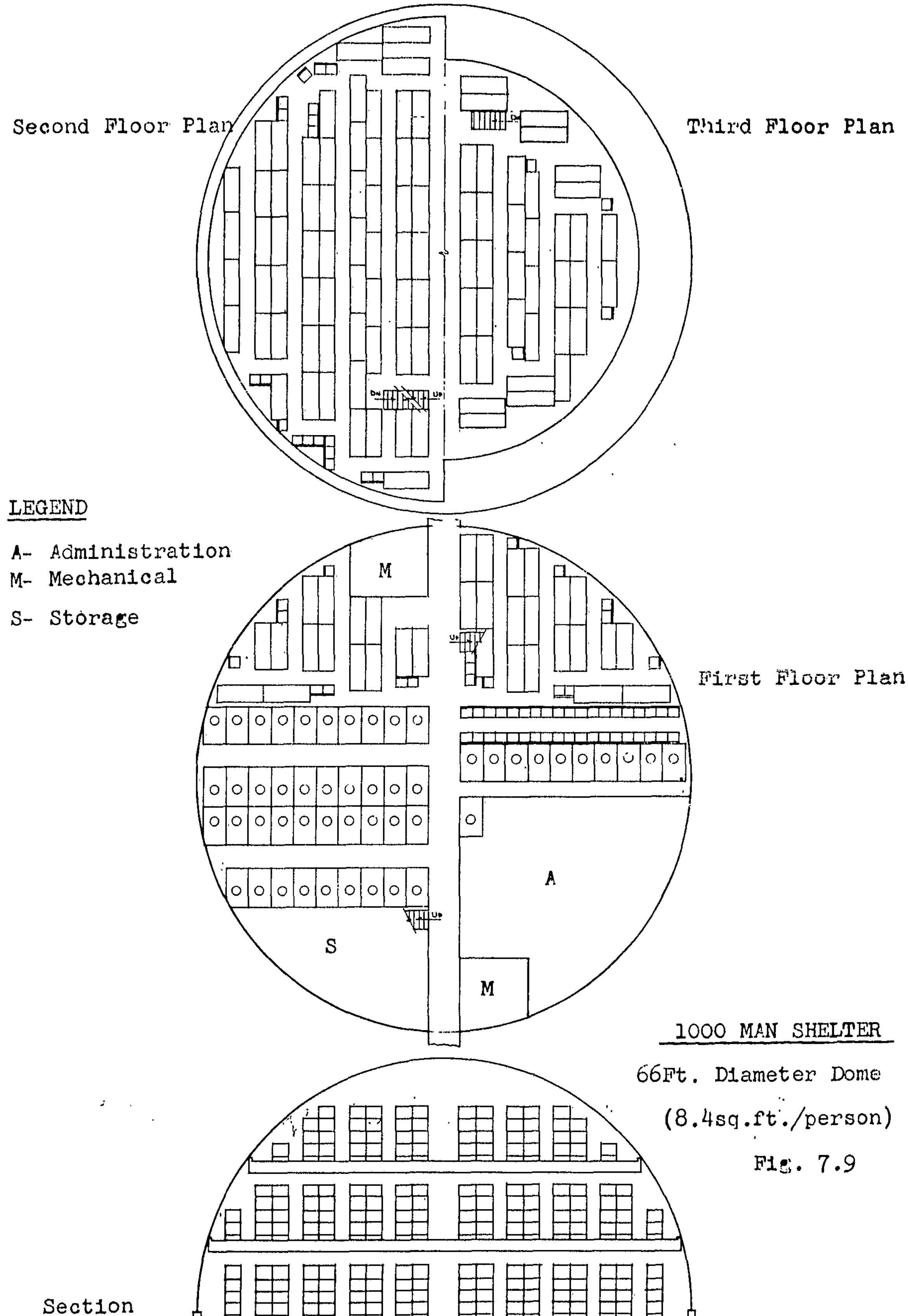
Section

500 MAN SHELTER

55 Ft. Diameter Dome

(8.6sq.ft./person)

Fig. 7.8



1000 MAN SHELTER

66Ft. Diameter Dome

(8.4sq.ft./person)

Fig. 7.9

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APPENDICES

Appendix A-1

Concrete costs for arch and dome construction were estimated by computing quantities of formwork, concrete and reinforcing steel for a 100-person capacity arch and dome respectively. These costs were used for all subsequent estimates of arches and domes.

Dome

Concrete	17.9 c.y.	@ $ 25	=	$448
Reinf. Steel	1.78 tons	@ $250	=	$445
Formwork				
1st 45°	2720 s.f.			
remainder	570 s.f.			
Total	3290 s.f.	@ $ 0.80	=	$2630

Total cost of 17.9 c.y. = $3523

Cost per c.y. including forms and reinf. steel = $ 197

Say $200

Arch

Concrete	18.4 c.y.	@ $ 25	=	$460
Reinf. Steel	1.83 tons	@ $250	=	$457
Formwork				
1st 45°	1698 s.f.			
remainder	851 s.f.			
Total	2549 s.f.	@ $ 0.65	=	$1660

Total cost of 18.4 c.y. = $2577

Cost per c.y. including forms and reinf. steel

= $140

Appendix B-1

Comparison Between 4- and 5- High Bunks for Rectangular Structures

The difference between 4- and 5- high is o.25 sq. ft. per person maximum. (See Table B-1)

B-1.1 For the 100-man shelter (25'-4" x 32'-0", when 4-high), 35 psi.

Gain due to 5-high - 25 sq. ft. @ $7 $175

Loss due to 5-high

Perimeter = (25'-4" + 32'-0")2 = approx. 115'

Need $\frac{115 \times 20/12 \times 10/12}{27} = 5.9$ cu. yds. of wall concrete

$\frac{810 \times 20/12}{27} = 50$ cu. yds. of excavation and backfill

$\frac{115 \times 20/12}{9} = 21$ sq.yds. of waterproofing

Additional column lengths are neglected.

Cost Summary:

Wall Concrete	5.9 cu. yds. @ $55 =	$324
Excavation and Backfill	50 cu. yds. @$1.77=	$ 89
Waterproofing	21 sq. yds. @$3.20=	$ 67
	Total	$480

Conclusion: 4-high less costly

Table B-1

Area Requirements for Bunking* and Seating
Including Aisle Space

No. of Tiers High	Bunk Area Per Person	Seat Area Per Person	Total Area Per Person
1	22.00	-	22.00
2	11.00	-	11.00
3	7.35	-	7.35
4	5.50	-	5.50
5	4.40	0.85	5.25

* Assuming convertible bunk system accomodating four people sitting. 5-high bunking requires one seat per 5 shelterees.

B-1.2 For the 100-man shelter, 60 psi

Gain due to 5-high - 25 sq. ft. @ \$14.20 \$355

Loss due to 5-high

Loss will be slightly greater than for 35 psi case, so we may conclude that 4-high is less costly at 60psi.

B-1.3 For the 500-man shelter (62'-0" x 63'-4", when 4-high), 35 psi

Gain due to 5-high- 125 sq. ft. @ \$6.90 \$863

Loss due to 5-high

Perimeter = (62'-0" + 63'-4")2 = approx. 250'

Need $\frac{250 \times 20/12 \times 10/12}{27}$ = 13 cu. yds. of wall concrete

$\frac{3920 \times 20/12}{27}$ = 242 cu. yds. of excavation and backfill

$\frac{250 \times 20/12}{9}$ = 46 sq.yds. of waterproofing

B-1.3 Continued

Cost Summary:

Wall Concrete	13 cu. yds. @	$55	$715
Excavation and Backfill	242 cu. yds.@	1.77	428
Waterproofing	46 sq. yds.@	3.20	147
	Total		$1290

Conclusion: 4-high less costly

B-1.4 For the 500-man shelter, 60 psi

Gain due to 5-high - 125 sq. ft. @ $11 $1375

Loss due to 5-high

Need $\frac{250 \times 20/12 \times 16/12}{27}$ = 21 cu. yds. of wall concrete

Other quantities are same as for B-1.3

Cost Summary:

Wall concrete	21 cu. yds. @	$55	$1155
Excavation and Backfill			428
Waterproofing			147
	Total		$1730

Conclusion: 4-high less costly

B-1.5 For the 1000-man shelter (84'-0" x 88'-8", when 4-high), 35 psi

Gain due to 5-high - 250 sq. ft. @ $6.30 $1575

Loss due to 5-high

Perimeter = (84'-0" = 88'-8")2 = Approx. 345'

B-1.5 Continued

Need $\frac{345 \times 20/12 \times 10/12}{27}$ = 18 cu. yds. of wall concrete

$\frac{7450 \times 20/12}{27}$ = 460 cu. yds. of excavation and backfill

$\frac{345 \times 20/12}{9}$ = 64 sq. yds. of waterproofing

Cost Summary:

Wall Concrete	18 cu. yds. @ $55	$ 990
Excavation and Backfill	460 cu. yds. @ 1.77	815
Waterproofing	64 sq. yds. @ 3.20	205
	Total	$2010

Conclusion: 4-high less costly

B-1.6 For the 1000-man shelter, 60 psi

Gain due to 5-high - 250 sq. ft. @ $10.25 = $2560

Loss due to 5-high

Need $\frac{345 \times 20/12 \times 16/12}{27}$ = 29.5 cu. yds. of wall concrete

Other quantities are same as for B-1.5

Cost Summary:

Wall Concrete	29.5 cu. yds. @ $55	$1620
Excavation and Backfill		815
Waterproofing		205
	Total	$2640

Conclusion: 5-high is not less costly than 4-high.

APPENDIX B-2

Costs of Steel and Concrete Arch Configurations were computed for various diameters. These costs are presented in the following tables.

TABLE B-2.1

STEEL ARCHES

PHYSICAL PROPERTIES AND COST DATA

100 CAPACITY

Diam.	Bunks High	Physical Properties: Length Ft.	Physical Properties: Area/Person Ft^2	Physical Properties: Vol./Person Ft^3	Cost per Person ($) 35 psi: Basic Arch	Cost per Person ($) 35 psi: Interm. Floors	Cost per Person ($) 35 psi: Total	Cost per Person ($) 60 psi: Basic Arch	Cost per Person ($) 60 psi: Interm. Floors	Cost per Person ($) 60 psi: Total
16	4	62.2	9.33	68.5	75	-	75	88	-	88
23	4	44.3	9.61	102.6	100	-	100	121	-	121
23	5	41.3	9.05	96.7	96	-	96	115	-	115
30	4	29.7	8.70	112.5	117	-	117	143	-	143
30	5	26.2	7.68	99.3	110	-	110	134	-	134
30	4-3	21.8	10.04	82.5	102	7	109	123	7	130

500 CAPACITY

Diam.	Bunks High	Physical Properties: Length Ft.	Physical Properties: Area/Person Ft^2	Physical Properties: Vol./Person Ft^3	Cost per Person ($) 35 psi: Basic Arch	Cost per Person ($) 35 psi: Interm. Floors	Cost per Person ($) 35 psi: Total	Cost per Person ($) 60 psi: Basic Arch	Cost per Person ($) 60 psi: Interm. Floors	Cost per Person ($) 60 psi: Total
16	4	296.7	8.92	65.6	58	-	58	69	-	69
23	4	210.3	9.12	97.4	67	-	67	84	-	84
23	5	201.3	8.74	93.2	65	-	65	81	-	81
30	4	141.8	8.31	107.2	68	-	68	83	-	83
30	5	127.8	7.50	97.0	62	-	62	76	-	76
30	4-3	99.2	9.13	75.2	51	6	57	62	6	68
35	4	116.2	7.96	120.6	74	-	74	89	-	89
35	5	111.2	7.60	115.2	71	-	71	86	-	86
35	4-4	77.3	8.52	80.0	54	6	60	65	6	71
35	5-3	76.6	8.61	79.5	54	6	60	65	6	71

TABLE B-2.1

STEEL ARCHES

PHYSICAL PROPERTIES AND COST DATA

500 CAPACITY (Cont'd)

44	4	86.3	7.40	140.8	86	-	86	121	-	121
44	5	82.7	7.08	135.0	86	-	86	118	-	118
44	4-4	51.5	7.90	84.0	64	6	70	86	6	92
44	4-5	50.1	7.69	82.0	63	6	69	84	6	90
44	5-4	49.9	7.67	81.6	63	6	69	84	6	90
44	5-5	50.2	7.72	82.0	63	6	69	84	6	90
49	4	81.8	7.76	159.4	105	-	105	144	-	144
49	5	78.0	7.42	152.2	101	-	101	139	-	139
49	4-4	43.8	7.92	85.5	72	7	79	96	7	103
49	4-5	42.2	7.64	82.2	71	7	78	94	7	101
49	5-4	46.0	8.04	89.8	74	7	81	99	7	106
49	5-5	45.6	7.96	89.0	73	7	80	99	7	106
49	4-4-4	34.8	8.34	68.0	65	9	74	85	9	94
49	4-5-3	37.0	8.29	72.2	66	9	75	87	9	96
49	5-4-3	40.0	8.76	78.0	69	9	78	91	9	100
57	4	66.2	7.32	184.5	119	-	119	169	-	169
57	5	63.7	7.04	177.4	117	-	117	165	-	165
57	4-4	37.2	8.18	104.0	88	8	96	120	8	128
57	4-5	38.2	8.38	106.5	89	8	97	122	8	130
57	5-4	40.3	8.70	112.5	92	8	100	126	8	134
57	5-5	35.0	7.58	98.0	86	8	94	117	8	125
57	4-4-4	27.0	8.43	75.2	77	10	87	103	10	113
57	4-4-5	27.0	8.43	75.2	77	10	87	103	10	113
57	4-5-4	28.3	8.69	79.0	79	10	89	105	10	115
57	4-5-5	27.8	8.52	77.4	78	10	88	104	10	114
57	5-4-4	28.1	8.56	78.5	79	10	89	105	10	115

TABLE B-2.1

STEEL ARCHES

PHYSICAL PROPERTIES AND COST DATA

500 CAPACITY (Cont'd)

57	5-4-5	28.0	8.53	78.0	78	10	88	105	10	115
57	5-5-4	28.5	8.51	79.4	79	10	89	106	10	116

1,000 CAPACITY

16	4	580.3	8.70	63.8	54	-	54	65	-	65
23	4	419.3	9.10	97.1	64	-	64	80	-	80
23	5	401.3	8.71	93.0	61	-	61	76	-	76
30	4	282.0	8.26	106.8	62	-	62	76	-	76
30	5	253.8	7.44	96.0	56	-	56	69	-	69
30	4-3	196.0	9.02	74.3	45	6	51	55	6	61
35	4	231.7	7.95	119.5	65	-	65	80	-	80
35	5	221.3	7.56	109.5	63	-	63	76	-	76
35	4-4	150.3	8.29	77.9	45	6	51	55	6	61
35	5-3	149.9	8.43	77.6	45	6	51	55	6	61
44	4	169.7	7.28	138.5	74	-	74	104	-	104
44	5	162.8	6.95	133.0	71	-	71	100	-	100
44	4-4	100.7	7.73	82.2	50	6	56	68	6	74
44	4-5	98.3	7.54	80.3	49	6	55	67	6	73
44	5-4	97.8	7.50	79.8	48	6	54	67	6	73
44	5-5	97.3	7.46	79.5	48	6	54	67	6	73
49	4	161.3	7.66	157.3	86	-	86	122	-	122
49	5	154.2	7.32	150.5	83	-	83	118	-	118
49	4-4	85.3	7.72	83.1	54	7	61	74	7	81

TABLE B-2.1

STEEL ARCHES

PHYSICAL PROPERTIES AND COST DATA

1,000 CAPACITY (Cont'd)

49	4-5	83.8	7.58	81.7	53	7	60	73	7	80
49	5-4	91.3	7.99	89.0	56	7	63	78	7	85
49	5-5	89.2	7.81	87.0	55	7	62	77	7	84
49	4-4-4	67.0	8.04	65.4	46	9	55	63	9	72
49	4-5-3	71.2	8.01	69.5	47	9	56	65	9	74
49	5-4-3	77.3	8.46	75.4	50	9	59	69	9	78
57	4	130.8	7.23	182.0	94	-	94	140	-	140
57	5	125.0	6.91	174.0	91	-	91	135	-	135
57	4-4	71.8	7.89	101.1	63	8	71	89	8	97
57	4-5	70.2	7.70	99.0	62	8	70	88	8	96
57	5-4	70.2	7.60	99.0	62	8	70	88	8	96
57	5-5	69.2	7.48	97.5	61	8	69	87	8	95
57	4-4-4	56.5	8.83	78.7	54	11	65	76	11	87
57	4-4-5	55.0	8.60	76.6	54	10	64	75	10	85
57	4-5-4	54.8	8.42	76.5	54	10	64	75	10	85
57	4-5-5	55.0	8.46	76.6	54	10	64	75	10	85
57	5-4-4	54.7	8.32	76.2	54	10	64	75	10	85
57	5-4-5	54.0	8.23	75.2	53	10	63	74	10	84
57	5-5-4	55.5	8.29	77.3	54	10	64	76	10	86

TABLE B-2.2

CONCRETE ARCHES

PHYSICAL PROPERTIES AND COST DATA

100 CAPACITY

		PHYSICAL PROPERTIES			COST PER PERSON ($) 35 psi			COST PER PERSON ($) 60 psi		
Diam.	Bunks High	Length Ft.	Area/ Person Ft^2	Vol./ Person Ft^3	Basic Arch	Interm. Floors	Total	Basic Arch	Interm. Floors	Total
16	4	62.2	9.33	68.5	56	-	56	60	-	60
23	4	44.3	9.61	102.6	80	-	80	91	-	91
23	5	41.3	9.05	96.7	77	-	77	86	-	86
30	4	29.7	8.70	112.5	93	-	93	104	-	104
30	5	26.2	7.68	99.3	86	-	86	96	-	96
30	4-3	21.8	10.04	82.5	78	7	85	87	7	94

500 CAPACITY

		PHYSICAL PROPERTIES			COST PER PERSON ($) 35 psi			COST PER PERSON ($) 60 psi		
Diam.	Bunks High	Length Ft.	Area/ Person Ft^2	Vol./ Person Ft^3	Basic Arch	Interm. Floors	Total	Basic Arch	Interm. Floors	Total
16	4	296.7	8.92	65.6	46	-	46	49	-	49
23	4	210.3	9.12	97.4	58	-	58	66	-	66
23	5	201.3	8.74	93.2	56	-	56	64	-	64
30	4	141.8	8.31	107.2	60	-	60	69	-	69
30	5	127.8	7.50	97.0	55	-	55	63	-	63
30	4-3	99.2	9.13	75.2	44	6	50	50	6	56
35	4	116.2	7.96	120.6	66	-	66	75	-	75
35	5	111.2	7.60	115.2	64	-	64	72	-	72
35	4-4	77.3	8.52	80.0	47	6	53	54	6	60

TABLE B-2.2

CONCRETE ARCHES

PHYSICAL PROPERTIES AND COST DATA

500 CAPACITY (Cont'd)

35	5-3	76.6	8.61	79.5	47	7	54	53	7	60
44	4	86.3	7.40	140.8	78	-	78	89	-	89
44	5	82.7	7.08	135.0	76	-	76	86	-	86
44	4-4	51.5	7.90	84.0	53	7	60	61	7	68
44	4-5	50.1	7.69	82.0	53	6	59	60	6	66
44	5-4	49.9	7.67	81.6	53	6	59	60	6	66
44	5-5	50.2	7.72	82.0	53	6	59	60	6	66
49	4	81.8	7.76	159.4	95	-	95	108	-	108
49	5	78.0	7.42	152.2	92	-	92	104	-	104
49	4-4	43.8	7.92	85.5	62	7	69	70	7	77
49	4-5	42.2	7.64	82.2	60	7	67	68	7	75
49	5-4	46.0	8.04	89.8	63	7	70	72	7	79
49	5-5	45.6	7.96	89.0	63	7	70	71	7	78
49	4-4-4	34.8	8.34	68.0	54	9	63	60	9	69
49	4-5-3	37.0	8.29	72.2	56	9	65	63	9	72
49	5-4-3	40.0	8.76	78.0	59	9	68	66	9	75
57	4	66.2	7.32	184.5	113	-	113	124	-	124
57	5	63.7	7.04	177.4	110	-	110	121	-	121
57	4-4	37.2	8.18	104.0	78	8	86	85	8	93
57	4-5	38.2	8.38	106.5	79	8	87	87	8	95
57	5-4	40.3	8.70	112.5	82	8	90	89	8	97
57	5-5	35.0	7.58	98.0	75	8	83	82	8	90
57	4-4-4	27.0	8.43	75.2	66	10	76	72	10	82
57	4-4-5	27.0	8.43	75.2	66	10	76	72	10	82
57	4-5-4	28.3	8.69	79.0	67	10	77	73	10	83
57	4-5-5	27.8	8.52	77.4	67	10	77	73	10	83
57	5-4-4	28.1	8.56	78.5	67	10	77	73	10	83

TABLE B-2.2

CONCRETE ARCHES

PHYSICAL PROPERTIES AND COST DATA

500 CAPACITY (Cont'd)

57	5-4-5	28.0	8.52	78.0	67	10	77	73	10	83
57	5-5-4	28.5	8.51	79.4	68	10	78	74	10	84

1,000 CAPACITY

16	4	580.3	8.70	63.8	44	-	44	47	-	47
23	4	419.3	9.10	97.1	56	-	56	63	-	63
23	5	401.3	8.71	93.0	53	-	53	61	-	61
30	4	282.0	8.26	106.8	56	-	56	64	-	64
30	5	253.8	7.44	96.0	51	-	51	58	-	58
30	4-3	196.0	9.02	74.3	40	6	46	46	6	52
35	4	231.7	7.95	119.5	61	-	61	69	-	69
35	5	221.3	7.56	109.5	58	-	58	66	-	66
35	4-4	150.3	8.29	77.9	41	6	47	47	6	53
35	5-3	149.9	8.43	77.6	41	6	47	47	6	53
44	4	169.7	7.28	138.5	69	-	69	79	-	79
44	5	162.8	6.95	133.0	66	-	66	76	-	76
44	4-4	100.7	7.73	82.2	45	6	51	50	6	56
44	4-5	98.3	7.54	80.3	44	6	50	49	6	55
44	5-4	97.8	7.50	79.8	43	6	49	49	6	55
44	5-5	97.3	7.46	79.5	43	6	49	49	6	55
49	4	161.3	7.66	157.3	82	-	82	94	-	94
49	4-4	85.3	7.72	83.1	49	7	56	55	7	62
49	4-5	83.8	7.58	81.7	48	7	55	55	7	62

TABLE B-2.2

CONCRETE ARCHES

PHYSICAL PROPERTIES AND COST DATA

1,000 CAPACITY (Cont'd)

49	5-4	91.3	7.99	89.0	52	7	59	59	7	66
49	5-5	89.2	7.81	87.0	51	7	58	58	7	65
49	4-4-4	67.0	8.04	65.4	41	9	50	47	9	56
49	4-5-3	71.2	8.01	69.5	43	9	52	49	9	58
49	5-4-3	77.3	8.46	75.4	46	9	55	52	9	61
57	4	130.8	7.23	182.0	95	-	95	105	-	105
57	5	125.0	6.91	174.0	92	-	92	101	-	101
57	4-4	71.8	7.89	101.1	60	8	68	66	8	74
57	4-5	70.2	7.70	99.0	59	8	67	65	8	73
57	5-4	70.2	7.60	99.0	59	8	67	65	8	73
57	5-5	69.2	7.48	97.5	58	8	66	64	8	72
57	4-4-4	56.5	8.83	78.7	50	11	61	56	11	67
57	4-4-5	55.0	8.60	76.6	50	10	60	55	10	65
57	4-5-4	54.8	8.42	76.5	50	10	60	54	10	64
57	4-5-5	55.0	8.46	76.6	50	10	60	55	10	65
57	5-4-4	54.7	8.32	76.2	50	10	60	54	10	64
57	5-4-5	54.0	8.23	75.2	49	10	59	54	10	64
57	5-5-4	55.5	8.29	77.3	50	10	60	55	10	65

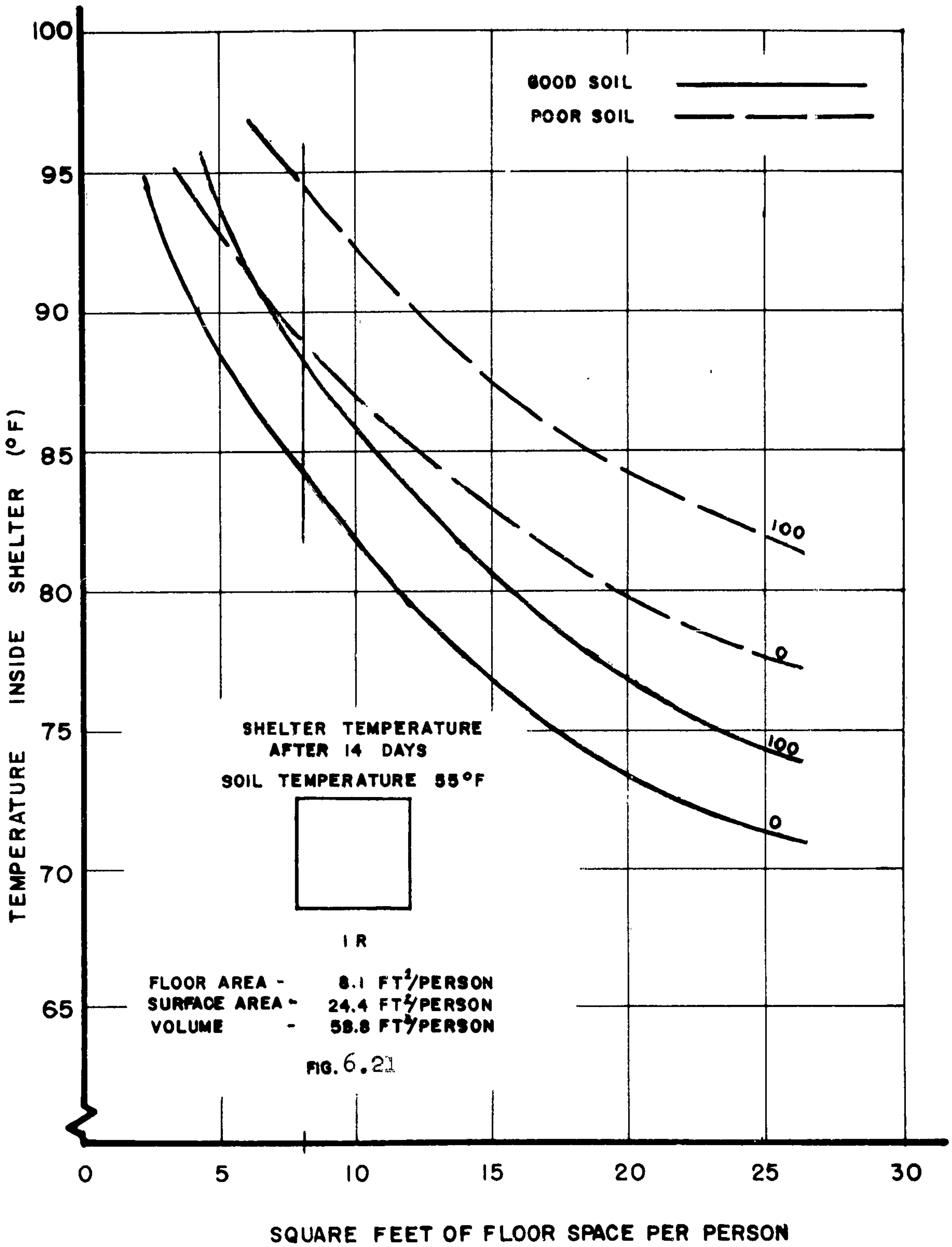
APPENDIX C-1

HEAT TRANSFER CURVES

for the

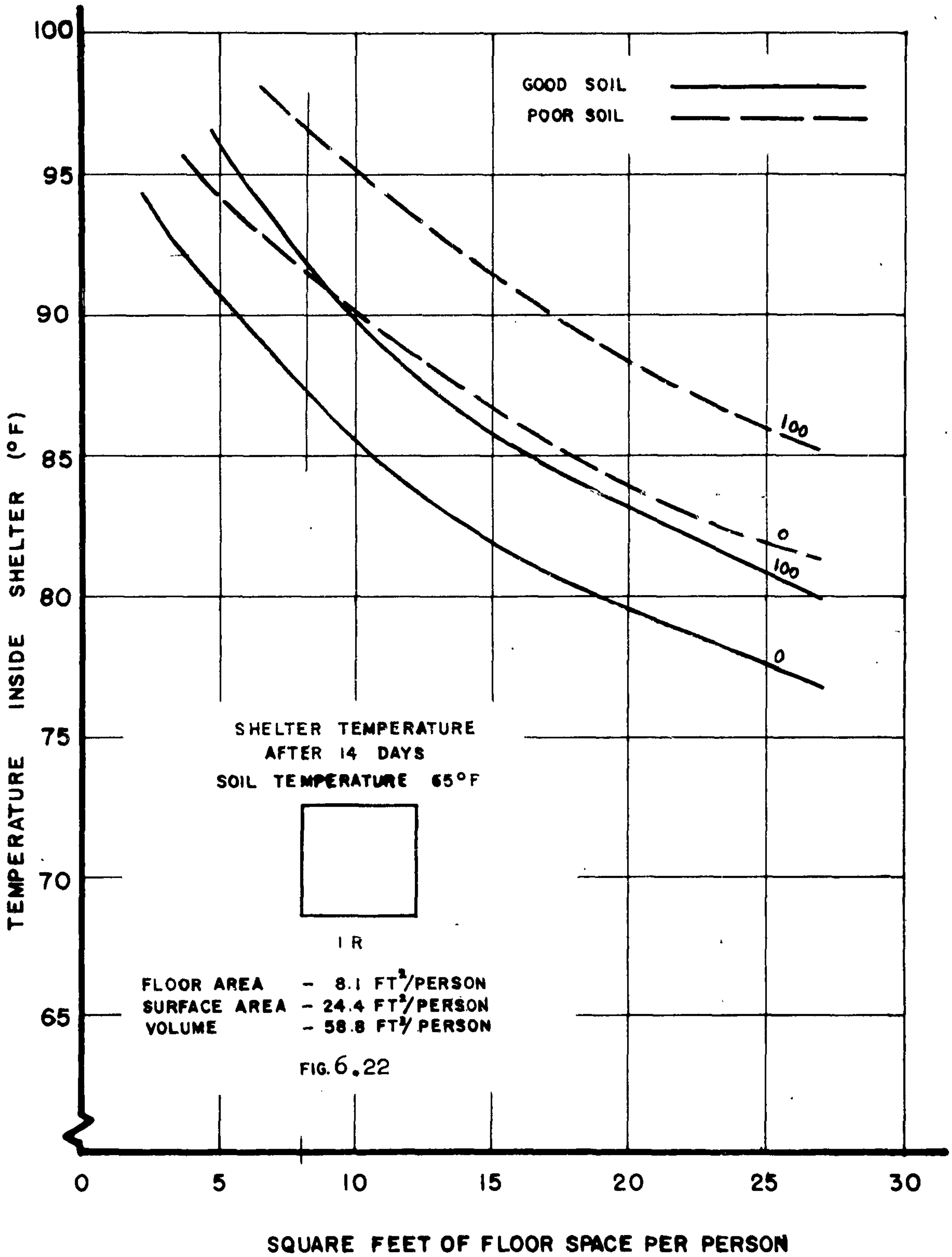
WARM-UP PERIOD (CURVE METHOD)

NOTE: On figures 6.21 through 6.40 the additional set of curves marked "100", are for 100 BTU/HR/PERSON additional sensible heat load.



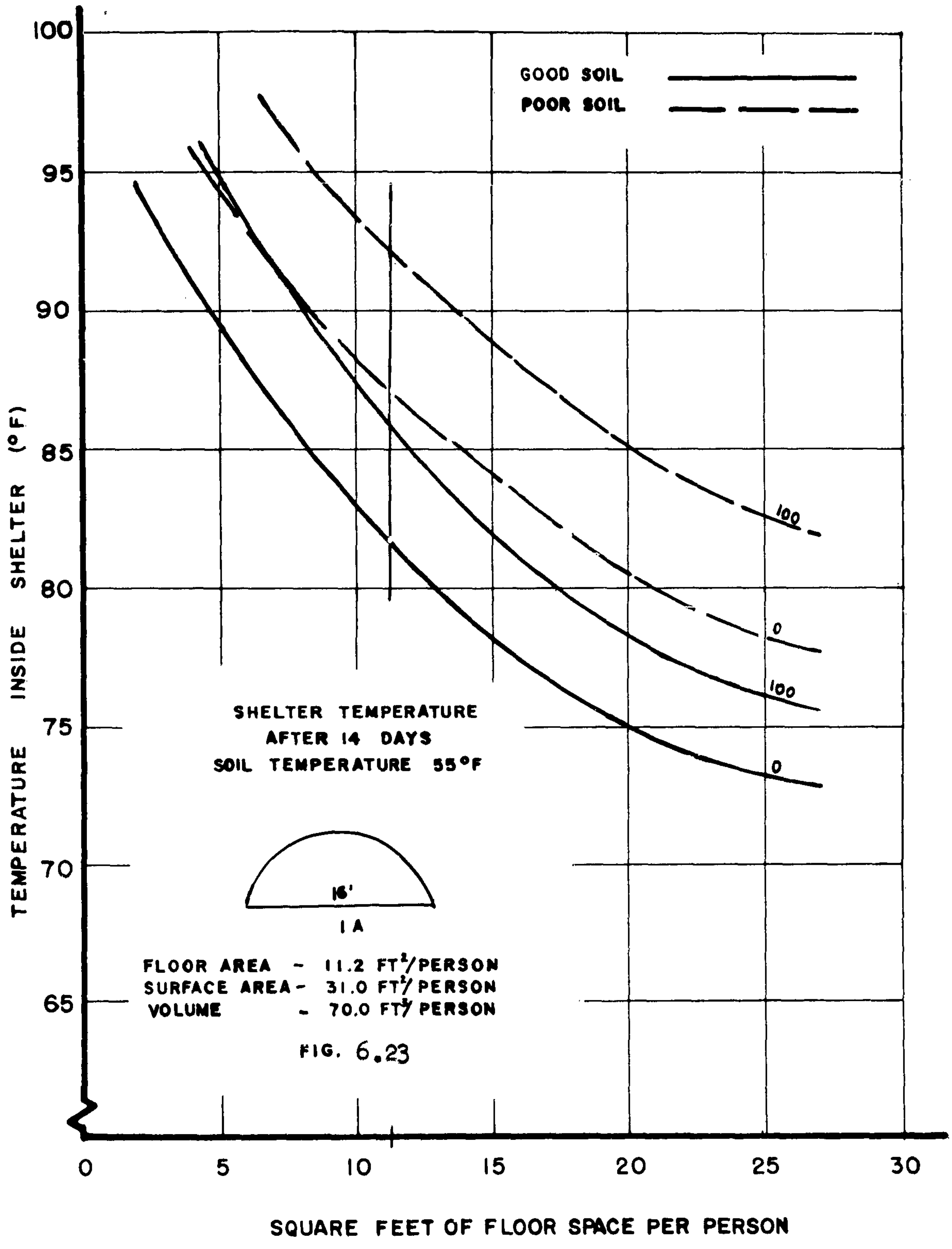
GOOD SOIL
POOR SOIL
100
0
100
0
SHELTER TEMPERATURE
AFTER 14 DAYS
SOIL TEMPERATURE 55°F
I R
FLOOR AREA - 8.1 FT²/PERSON
SURFACE AREA - 24.4 FT²/PERSON
VOLUME - 58.8 FT³/PERSON
TEMPERATURE INSIDE SHELTER (°F)
100
95
90
85
80
75
70
65
0
5
10
15
20
25
30
SQUARE FEET OF FLOOR SPACE PER PERSON

FIG. 6.21



GOOD SOIL
POOR SOIL
100
95
90
85
80
75
70
65
TEMPERATURE INSIDE SHELTER (°F)
100
0
100
0
SHELTER TEMPERATURE
AFTER 14 DAYS
SOIL TEMPERATURE 65°F
1 R
FLOOR AREA - 8.1 FT²/PERSON
SURFACE AREA - 24.4 FT²/PERSON
VOLUME - 58.8 FT³/PERSON
0
5
10
15
20
25
30
SQUARE FEET OF FLOOR SPACE PER PERSON

FIG. 6.22



GOOD SOIL
POOR SOIL
100
95
90
85
80
75
70
65
TEMPERATURE INSIDE SHELTER (°F)
100
0
100
0
SHELTER TEMPERATURE
AFTER 14 DAYS
SOIL TEMPERATURE 55°F
16'
I A
FLOOR AREA - 11.2 FT²/PERSON
SURFACE AREA - 31.0 FT²/PERSON
VOLUME - 70.0 FT³/PERSON
0
5
10
15
20
25
30
SQUARE FEET OF FLOOR SPACE PER PERSON

FIG. 6.23

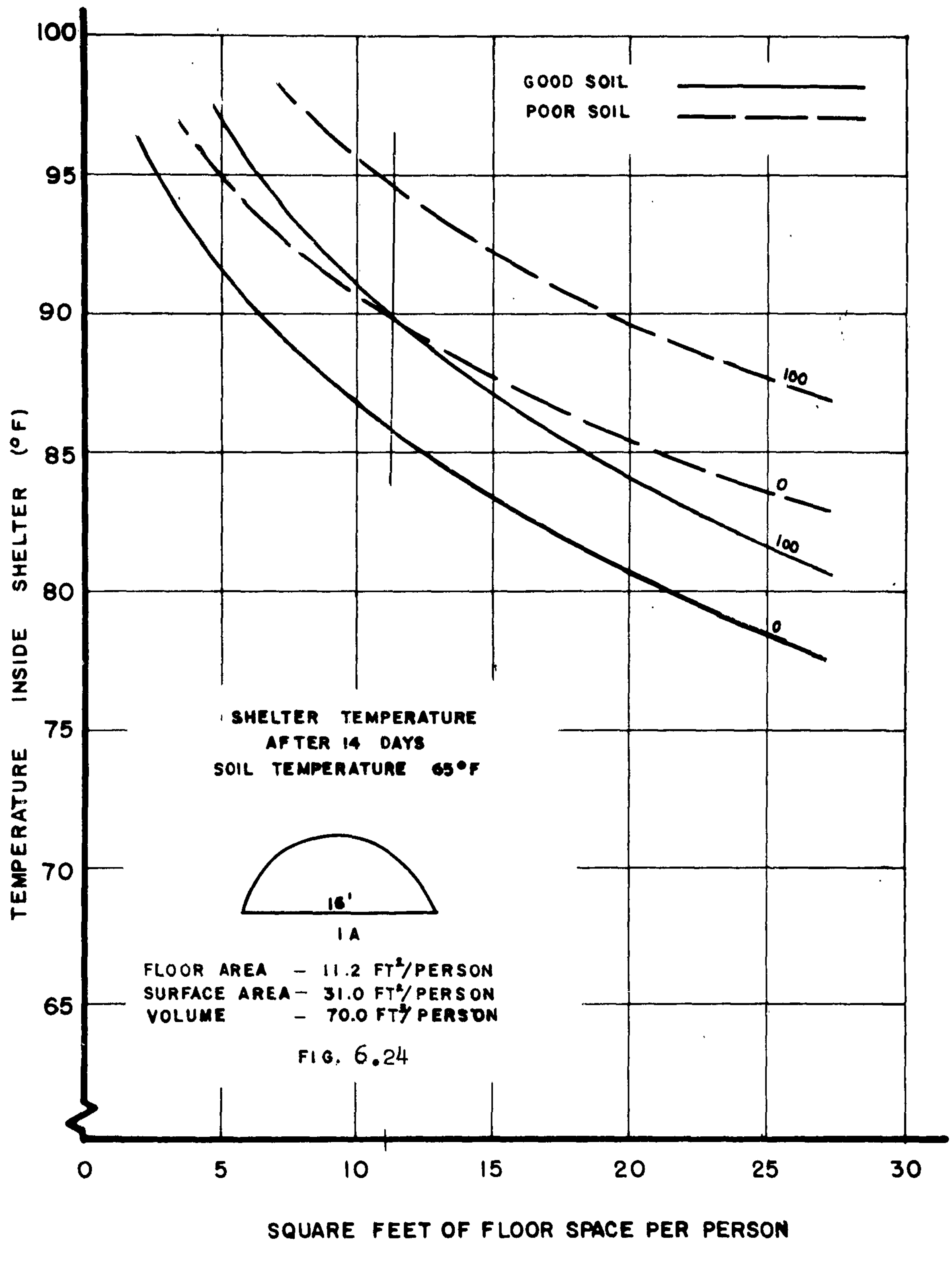

GOOD SOIL
POOR SOIL
100
0
100
0
100
95
90
85
80
75
70
65
TEMPERATURE INSIDE SHELTER (°F)
SHELTER TEMPERATURE
AFTER 14 DAYS
SOIL TEMPERATURE 65°F
16'
I A
FLOOR AREA – 11.2 FT²/PERSON
SURFACE AREA – 31.0 FT²/PERSON
VOLUME – 70.0 FT³/PERSON
0
5
10
15
20
25
30
SQUARE FEET OF FLOOR SPACE PER PERSON

FIG. 6.24

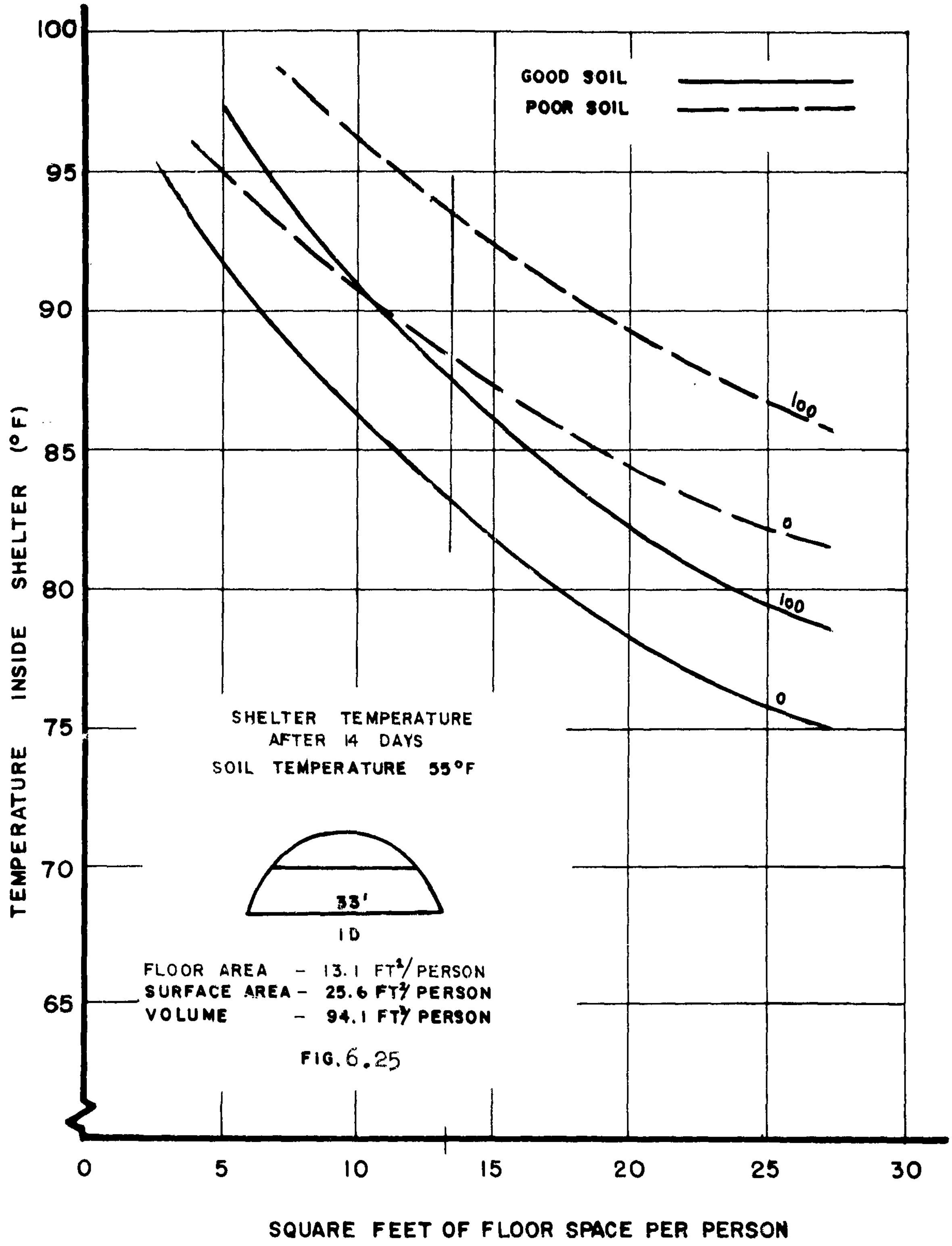
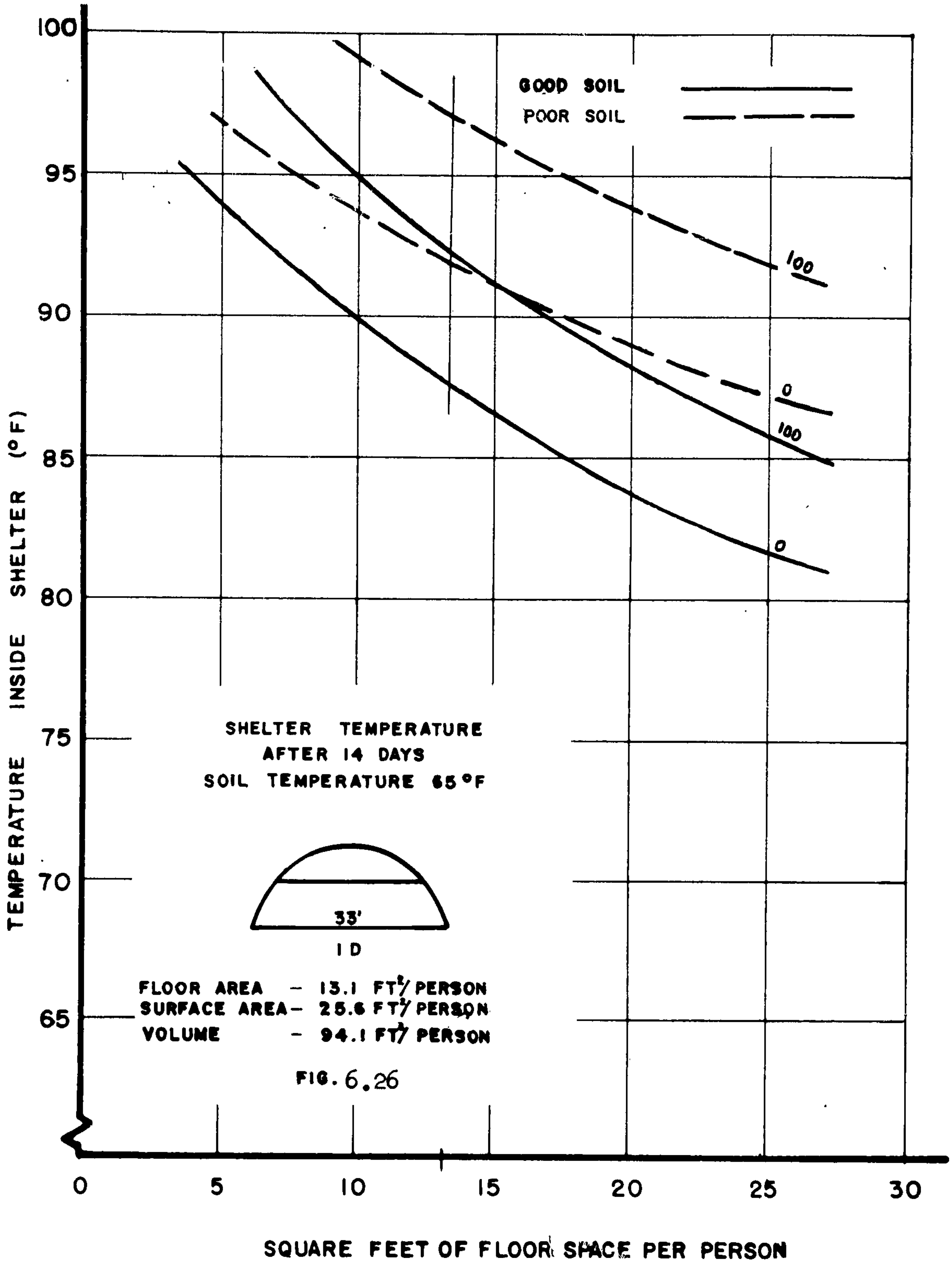
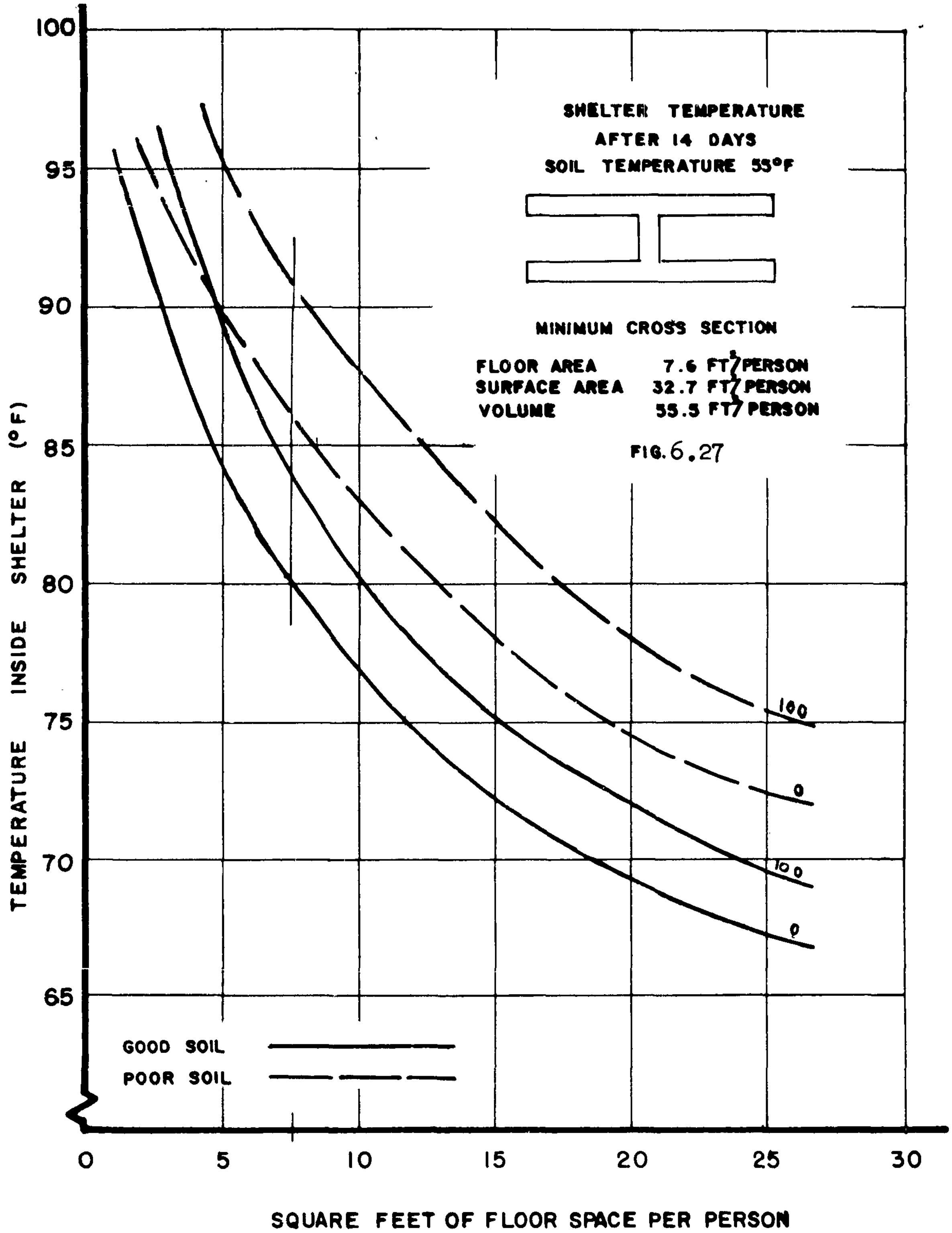

GOOD SOIL
POOR SOIL
100
0
100
0
SHELTER TEMPERATURE
AFTER 14 DAYS
SOIL TEMPERATURE 55°F
33'
ID
FLOOR AREA - 13.1 FT²/PERSON
SURFACE AREA - 25.6 FT²/PERSON
VOLUME - 94.1 FT³/PERSON
TEMPERATURE INSIDE SHELTER (°F)
100
95
90
85
80
75
70
65
0
5
10
15
20
25
30
SQUARE FEET OF FLOOR SPACE PER PERSON

FIG. 6.25



GOOD SOIL
POOR SOIL
100
0
100
0
100
95
90
85
80
75
70
65
TEMPERATURE INSIDE SHELTER (°F)
0
5
10
15
20
25
30
SQUARE FEET OF FLOOR SPACE PER PERSON
SHELTER TEMPERATURE
AFTER 14 DAYS
SOIL TEMPERATURE 65°F
33'
I D
FLOOR AREA - 13.1 FT²/PERSON
SURFACE AREA - 25.6 FT²/PERSON
VOLUME - 94.1 FT³/PERSON

FIG. 6.26


SHELTER TEMPERATURE
AFTER 14 DAYS
SOIL TEMPERATURE 55°F
MINIMUM CROSS SECTION
FLOOR AREA 7.6 FT²/PERSON
SURFACE AREA 32.7 FT²/PERSON
VOLUME 55.5 FT³/PERSON
TEMPERATURE INSIDE SHELTER (°F)
100
95
90
85
80
75
70
65
0
5
10
15
20
25
30
100
0
100
0
GOOD SOIL
POOR SOIL
SQUARE FEET OF FLOOR SPACE PER PERSON
FIG. 6.27

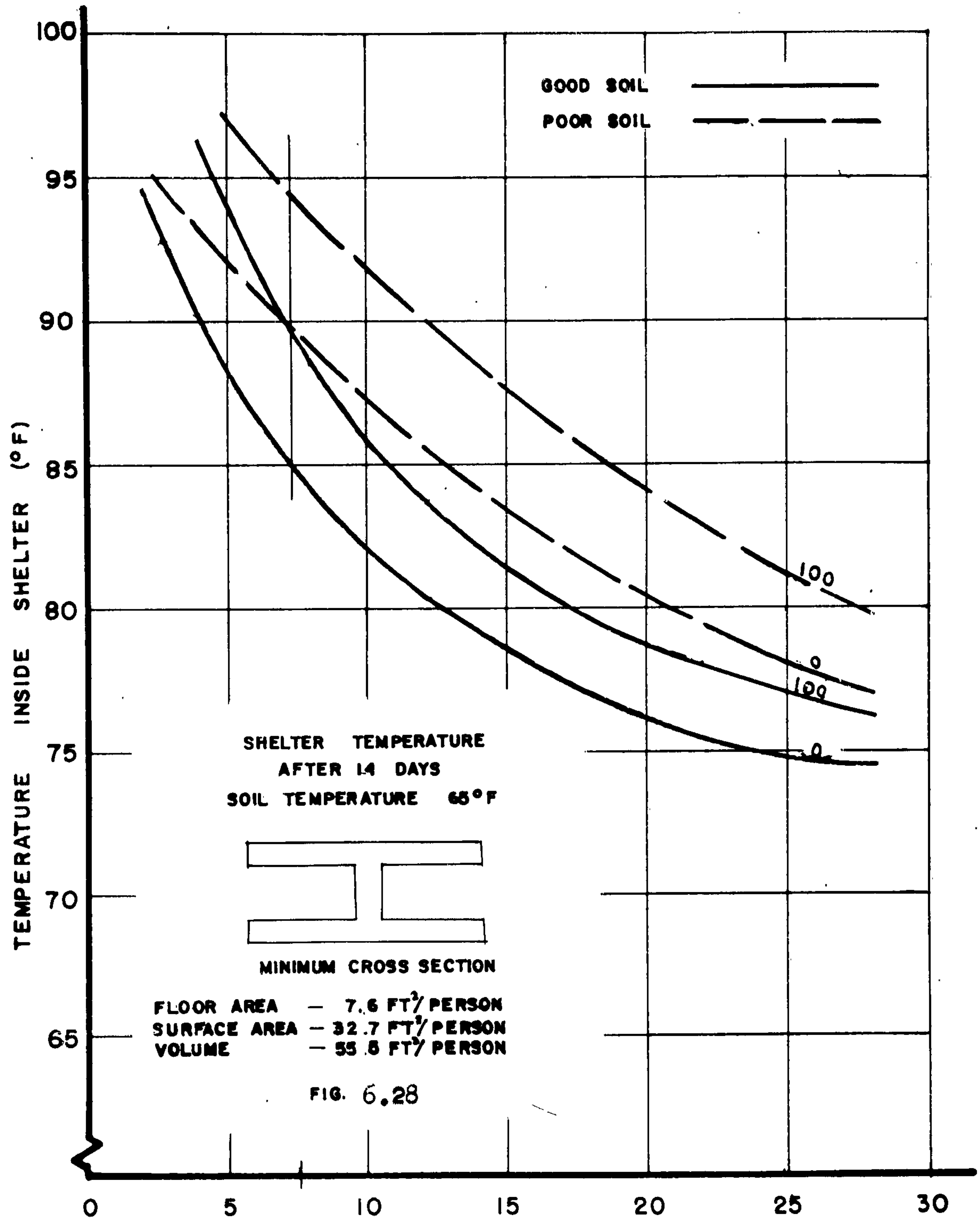

GOOD SOIL
POOR SOIL
100
95
90
85
80
75
70
65
TEMPERATURE INSIDE SHELTER (°F)
100
0
100
0
SHELTER TEMPERATURE
AFTER 14 DAYS
SOIL TEMPERATURE 65°F
MINIMUM CROSS SECTION
FLOOR AREA — 7.6 FT²/PERSON
SURFACE AREA — 32.7 FT²/PERSON
VOLUME — 55.5 FT³/PERSON
0
5
10
15
20
25
30
SQUARE FEET OF FLOOR SPACE PER PERSON

FIG. 6.28

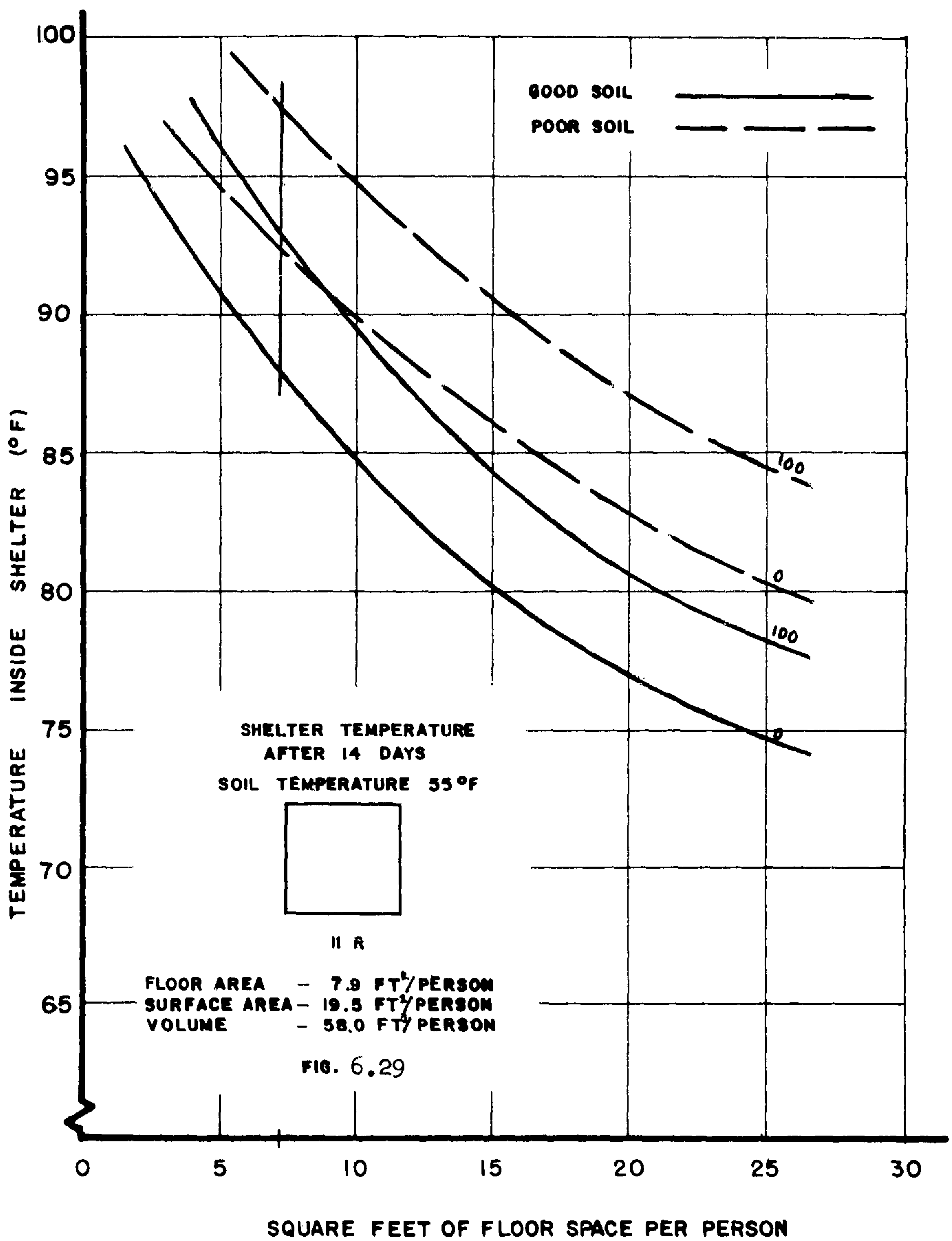
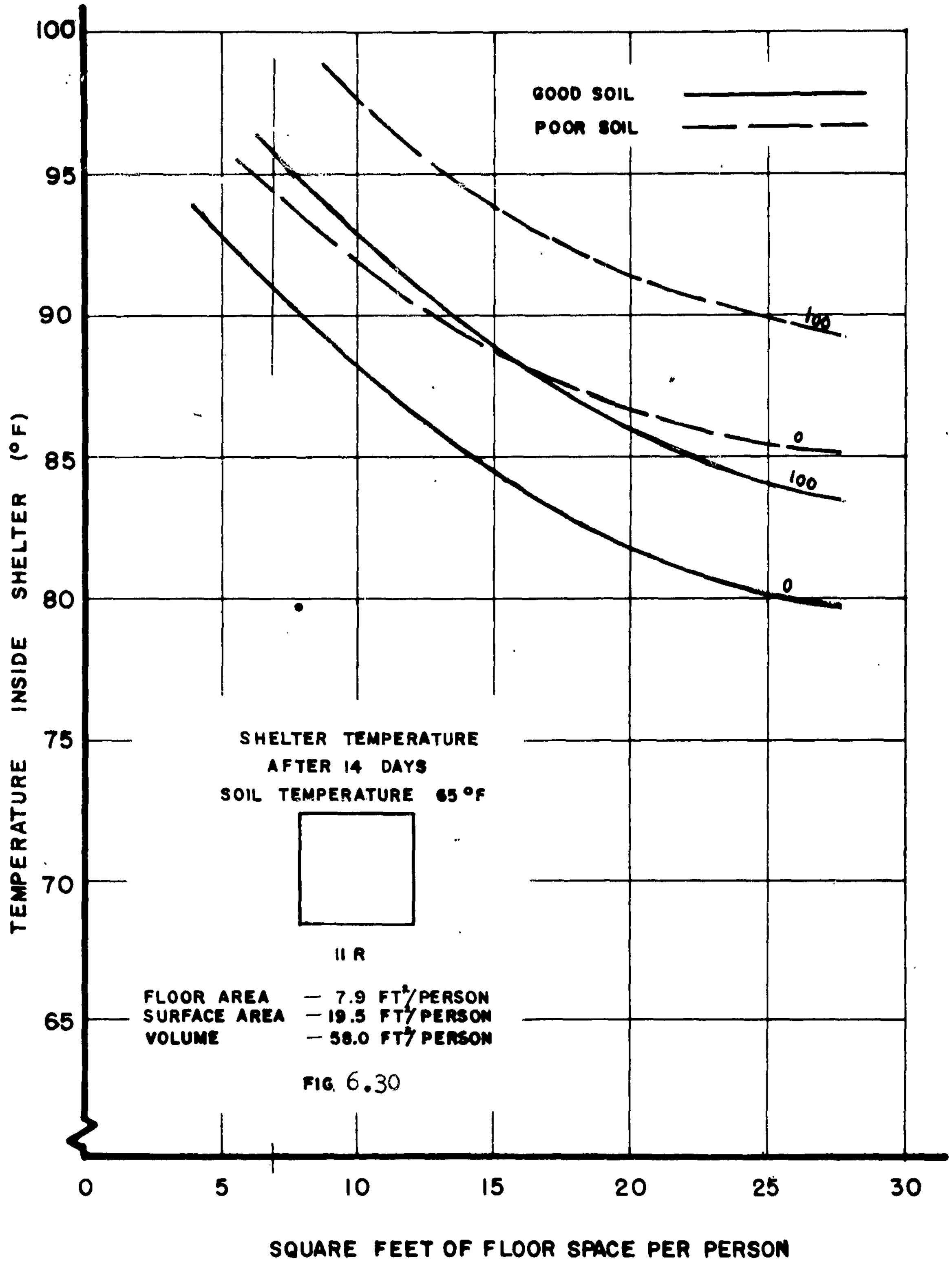

GOOD SOIL
POOR SOIL
100
0
100
0
SHELTER TEMPERATURE
AFTER 14 DAYS
SOIL TEMPERATURE 55°F
11 R
FLOOR AREA - 7.9 FT²/PERSON
SURFACE AREA - 19.5 FT²/PERSON
VOLUME - 58.0 FT³/PERSON
TEMPERATURE INSIDE SHELTER (°F)
100
95
90
85
80
75
70
65
0
5
10
15
20
25
30
SQUARE FEET OF FLOOR SPACE PER PERSON

FIG. 6.29


GOOD SOIL
POOR SOIL
100
0
100
0
TEMPERATURE INSIDE SHELTER (°F)
100
95
90
85
80
75
70
65
0
5
10
15
20
25
30
SHELTER TEMPERATURE
AFTER 14 DAYS
SOIL TEMPERATURE 65 °F
11 R
FLOOR AREA — 7.9 FT²/PERSON
SURFACE AREA — 19.5 FT²/PERSON
VOLUME — 58.0 FT³/PERSON
SQUARE FEET OF FLOOR SPACE PER PERSON
FIG. 6.30

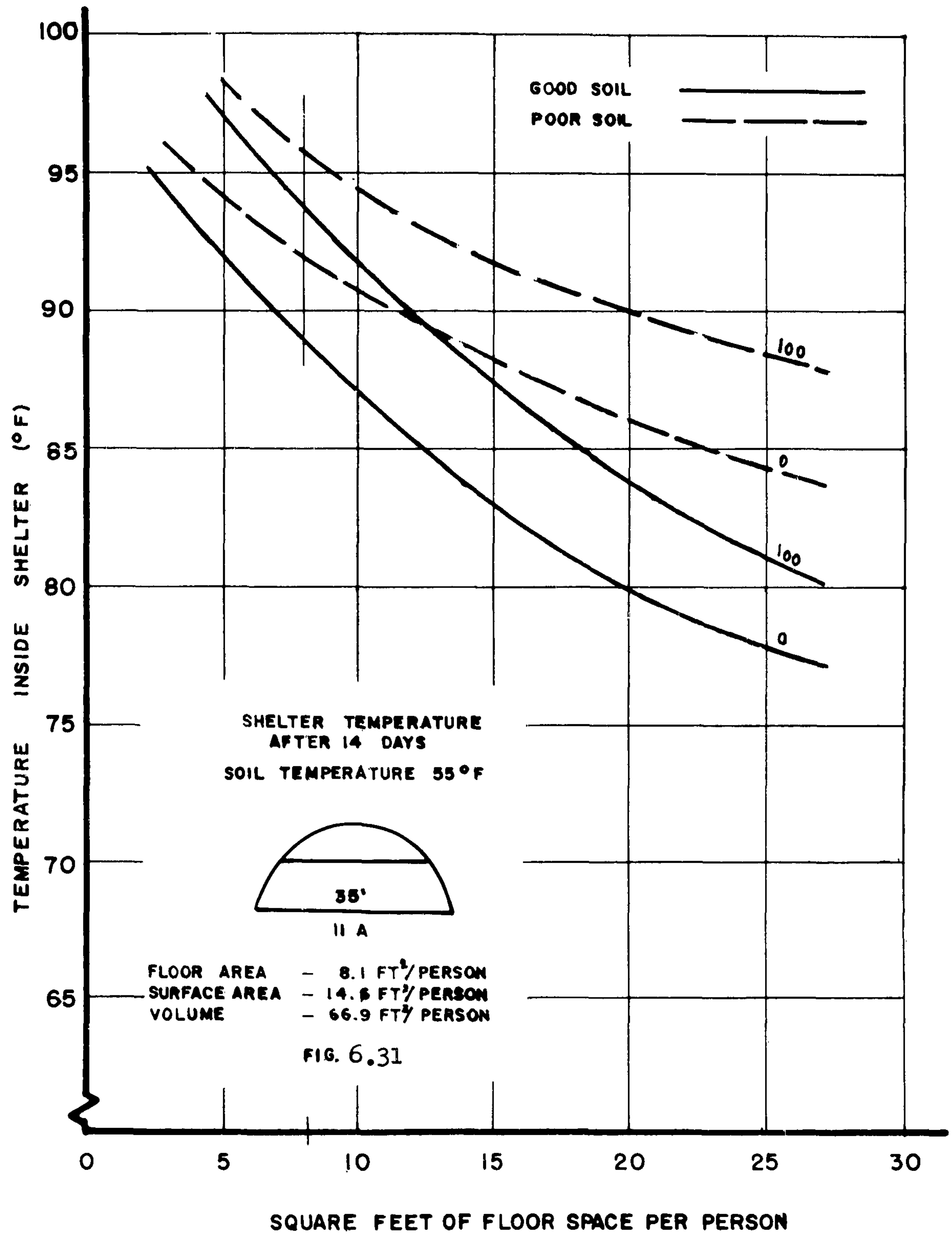
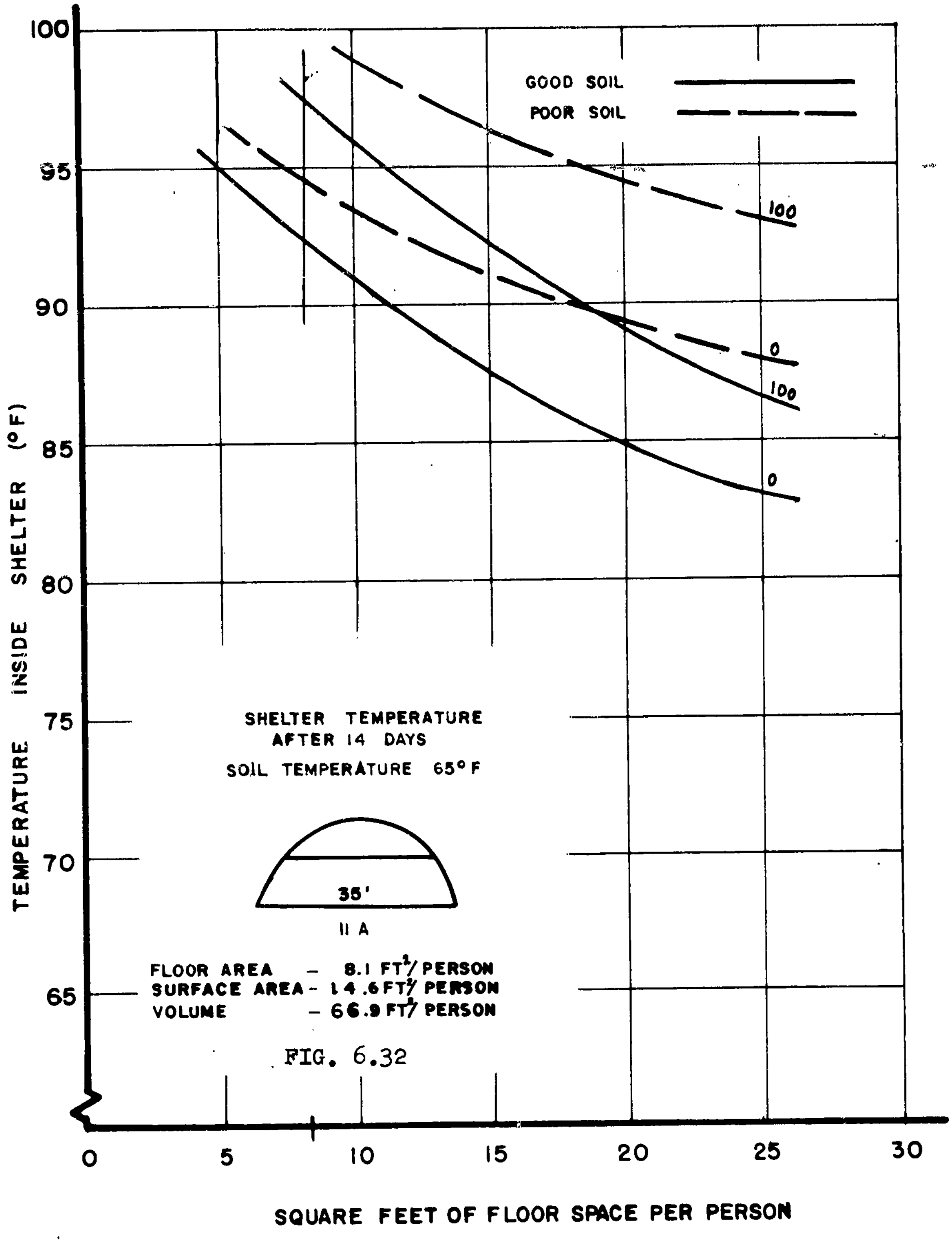

GOOD SOIL
POOR SOIL
100
0
100
0
SHELTER TEMPERATURE
AFTER 14 DAYS
SOIL TEMPERATURE 55°F
35'
11 A
FLOOR AREA – 8.1 FT²/PERSON
SURFACE AREA – 14.6 FT²/PERSON
VOLUME – 66.9 FT³/PERSON
TEMPERATURE INSIDE SHELTER (°F)
100
95
90
85
80
75
70
65
0
5
10
15
20
25
30
SQUARE FEET OF FLOOR SPACE PER PERSON

FIG. 6.31



GOOD SOIL
POOR SOIL
100
0
100
0
SHELTER TEMPERATURE
AFTER 14 DAYS
SOIL TEMPERATURE 65°F
35'
II A
FLOOR AREA – 8.1 FT²/ PERSON
SURFACE AREA – 14.6 FT²/ PERSON
VOLUME – 66.9 FT³/ PERSON
TEMPERATURE INSIDE SHELTER (°F)
SQUARE FEET OF FLOOR SPACE PER PERSON

FIG. 6.32

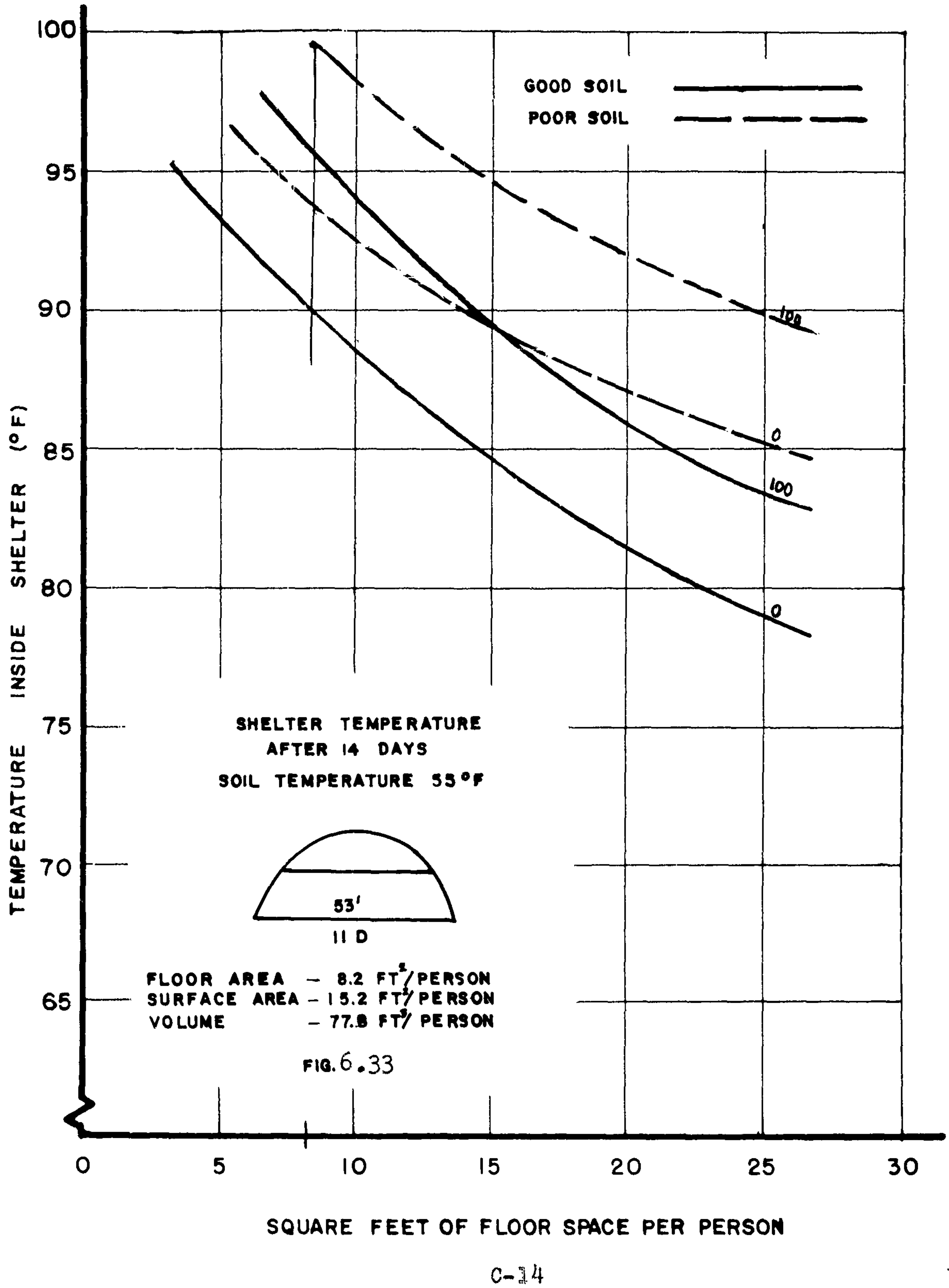
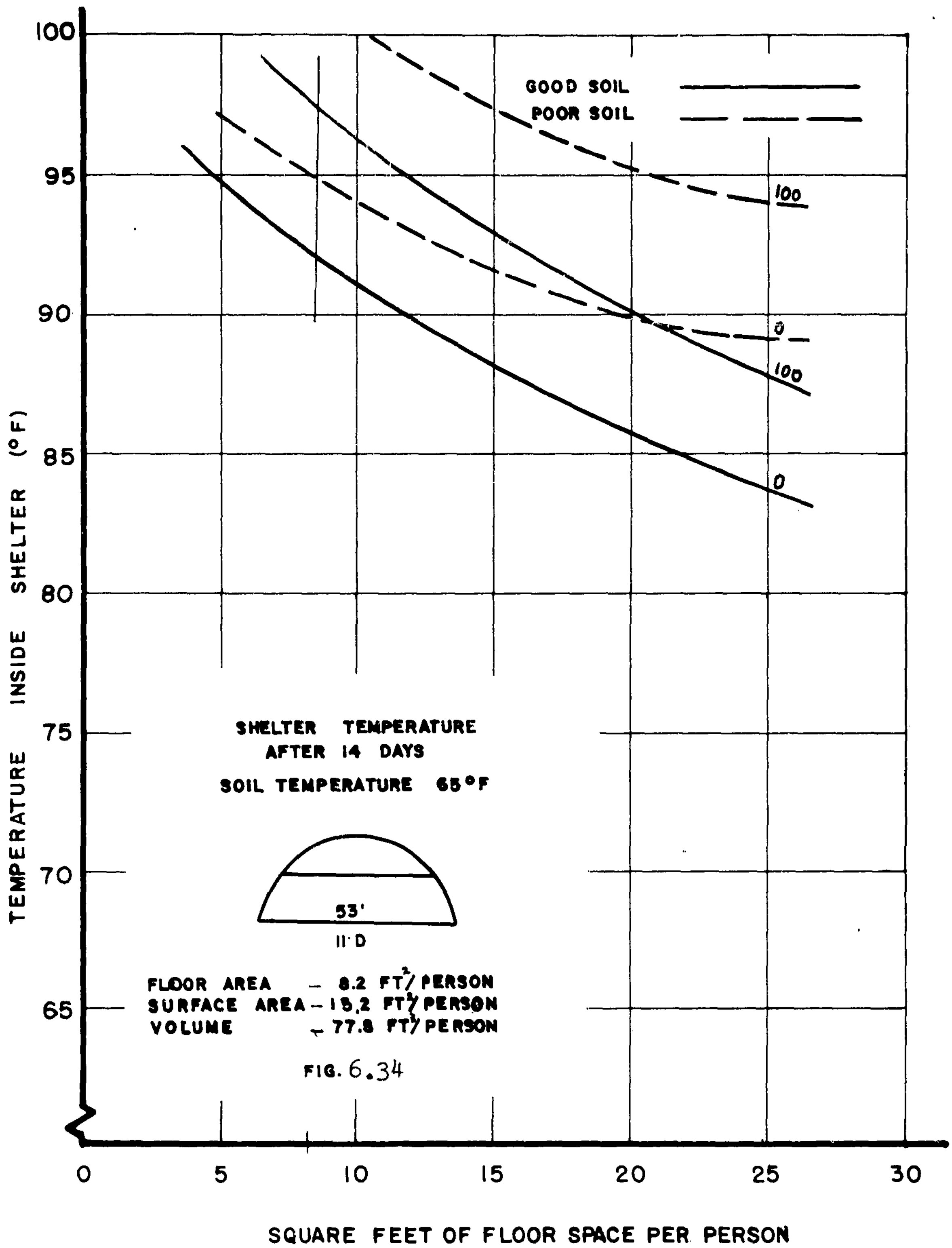

GOOD SOIL
POOR SOIL
100
0
100
0
SHELTER TEMPERATURE
AFTER 14 DAYS
SOIL TEMPERATURE 55°F
53'
11 D
FLOOR AREA – 8.2 FT²/PERSON
SURFACE AREA – 15.2 FT²/PERSON
VOLUME – 77.8 FT³/ PERSON
TEMPERATURE INSIDE SHELTER (°F)
100
95
90
85
80
75
70
65
0
5
10
15
20
25
30
SQUARE FEET OF FLOOR SPACE PER PERSON

FIG. 6.33



GOOD SOIL
POOR SOIL
100
0
100
0
100
95
90
85
80
75
70
65
TEMPERATURE INSIDE SHELTER (°F)
SHELTER TEMPERATURE
AFTER 14 DAYS
SOIL TEMPERATURE 65°F
53'
II·D
FLOOR AREA – 8.2 FT²/PERSON
SURFACE AREA – 15.2 FT²/PERSON
VOLUME – 77.8 FT³/PERSON
0
5
10
15
20
25
30
SQUARE FEET OF FLOOR SPACE PER PERSON

FIG. 6.34

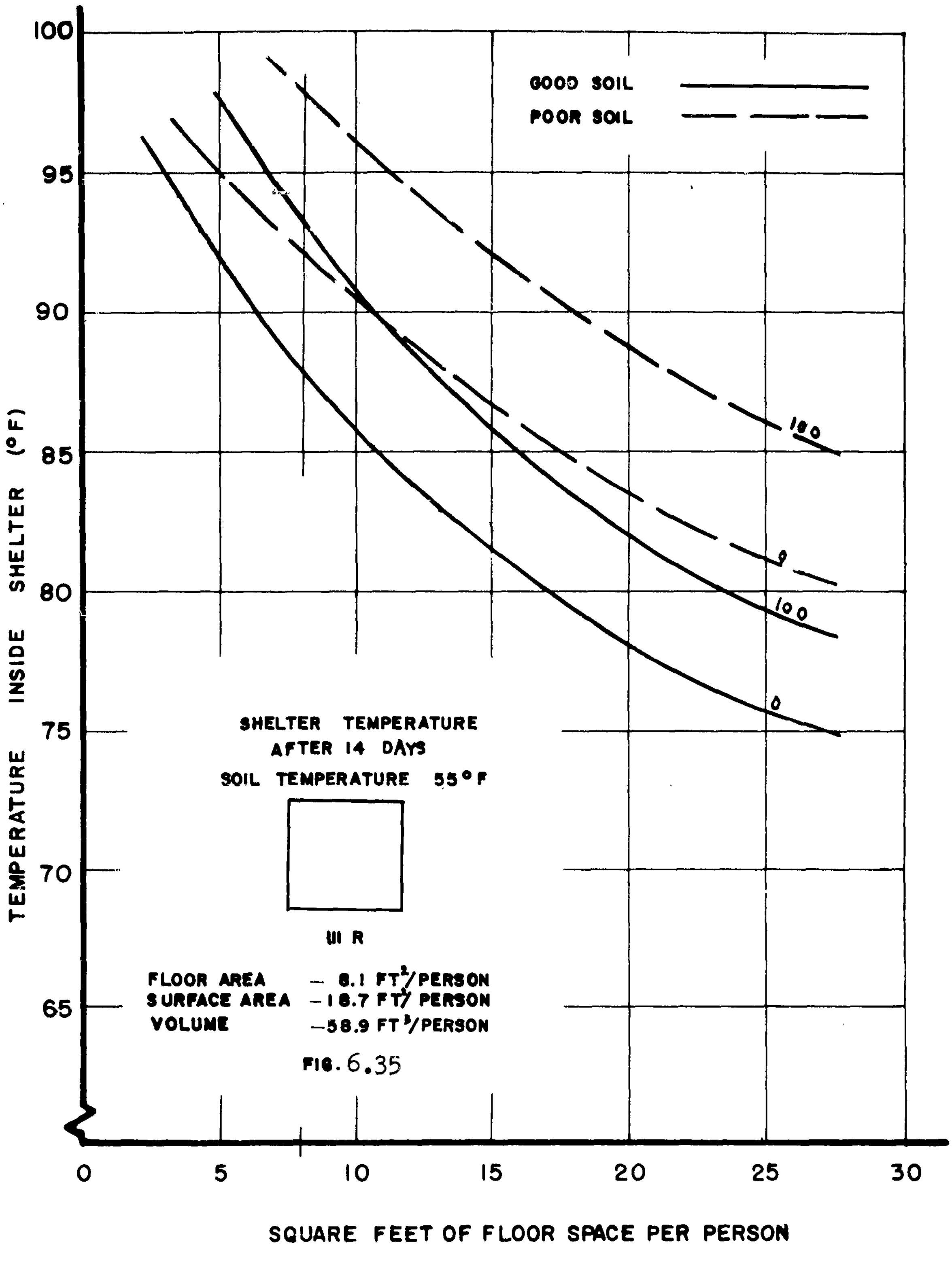

GOOD SOIL
POOR SOIL
100
95
90
85
80
75
70
65
0
5
10
15
20
25
30
TEMPERATURE INSIDE SHELTER (°F)
SQUARE FEET OF FLOOR SPACE PER PERSON
180
0
100
0
SHELTER TEMPERATURE
AFTER 14 DAYS
SOIL TEMPERATURE 55°F
III R
FLOOR AREA – 8.1 FT²/PERSON
SURFACE AREA – 18.7 FT²/ PERSON
VOLUME – 58.9 FT³/PERSON

FIG. 6.35

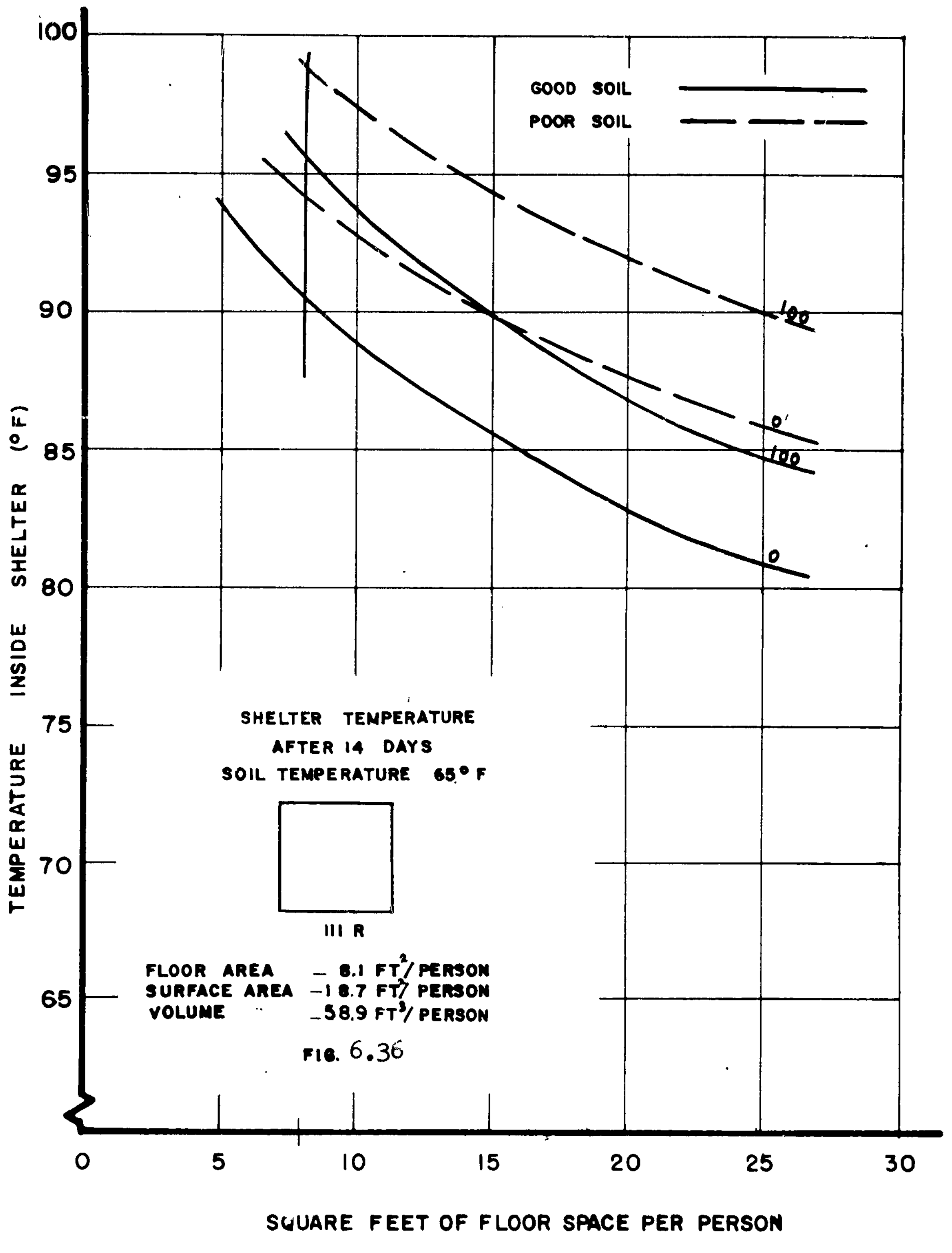

GOOD SOIL
POOR SOIL
100
90
95
85
80
75
70
65
0
5
10
15
20
25
30
100
0'
100
0
TEMPERATURE INSIDE SHELTER (°F)
SQUARE FEET OF FLOOR SPACE PER PERSON
SHELTER TEMPERATURE
AFTER 14 DAYS
SOIL TEMPERATURE 65° F
III R
FLOOR AREA – 8.1 FT²/ PERSON
SURFACE AREA – 18.7 FT²/ PERSON
VOLUME – 58.9 FT³/ PERSON

FIG. 6.36

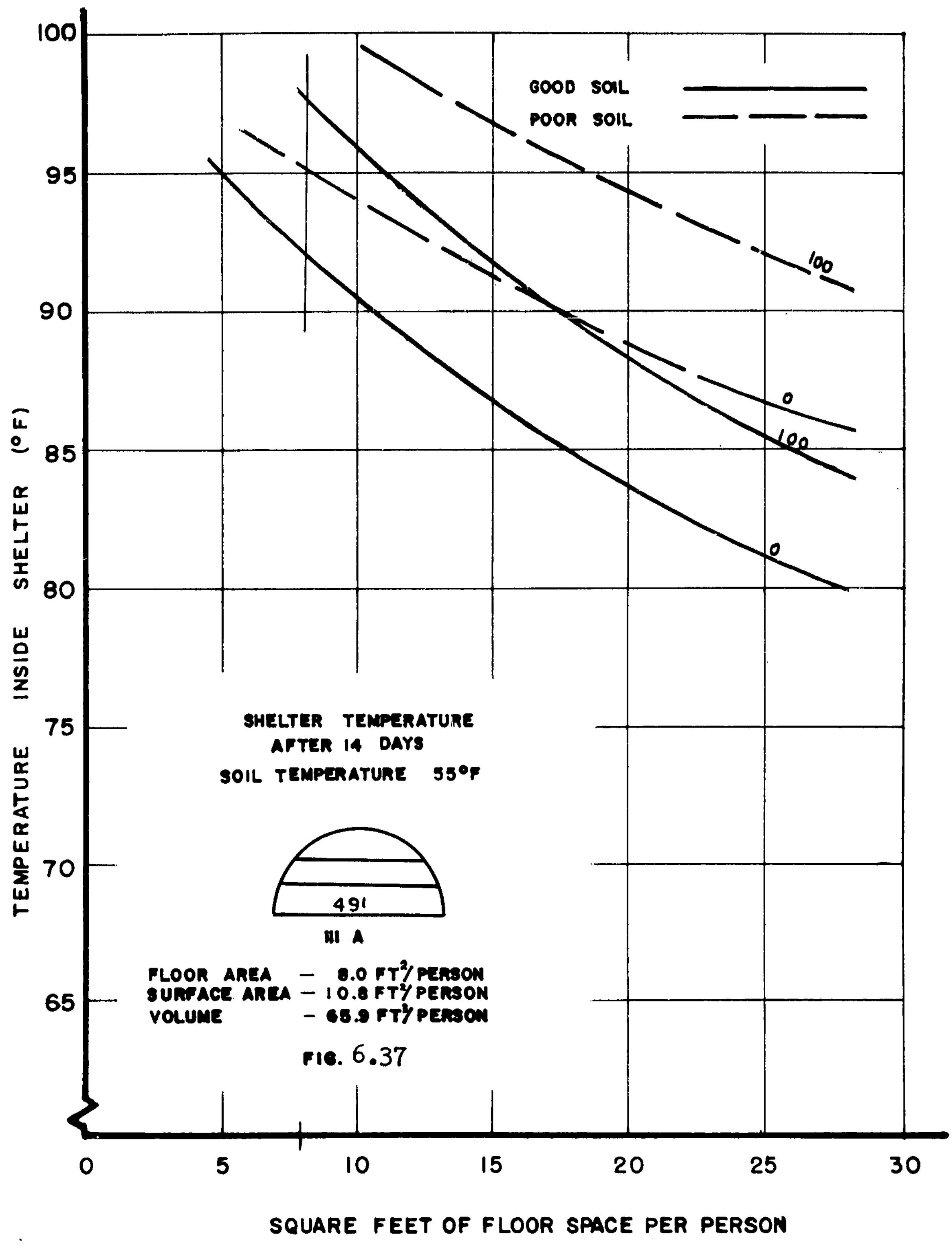

GOOD SOIL
POOR SOIL
100
0
100
0
100
95
90
85
80
75
70
65
TEMPERATURE INSIDE SHELTER (°F)
0
5
10
15
20
25
30
SQUARE FEET OF FLOOR SPACE PER PERSON
SHELTER TEMPERATURE
AFTER 14 DAYS
SOIL TEMPERATURE 55°F
49'
III A
FLOOR AREA – 8.0 FT²/PERSON
SURFACE AREA – 10.8 FT²/PERSON
VOLUME – 65.9 FT³/PERSON

FIG. 6.37

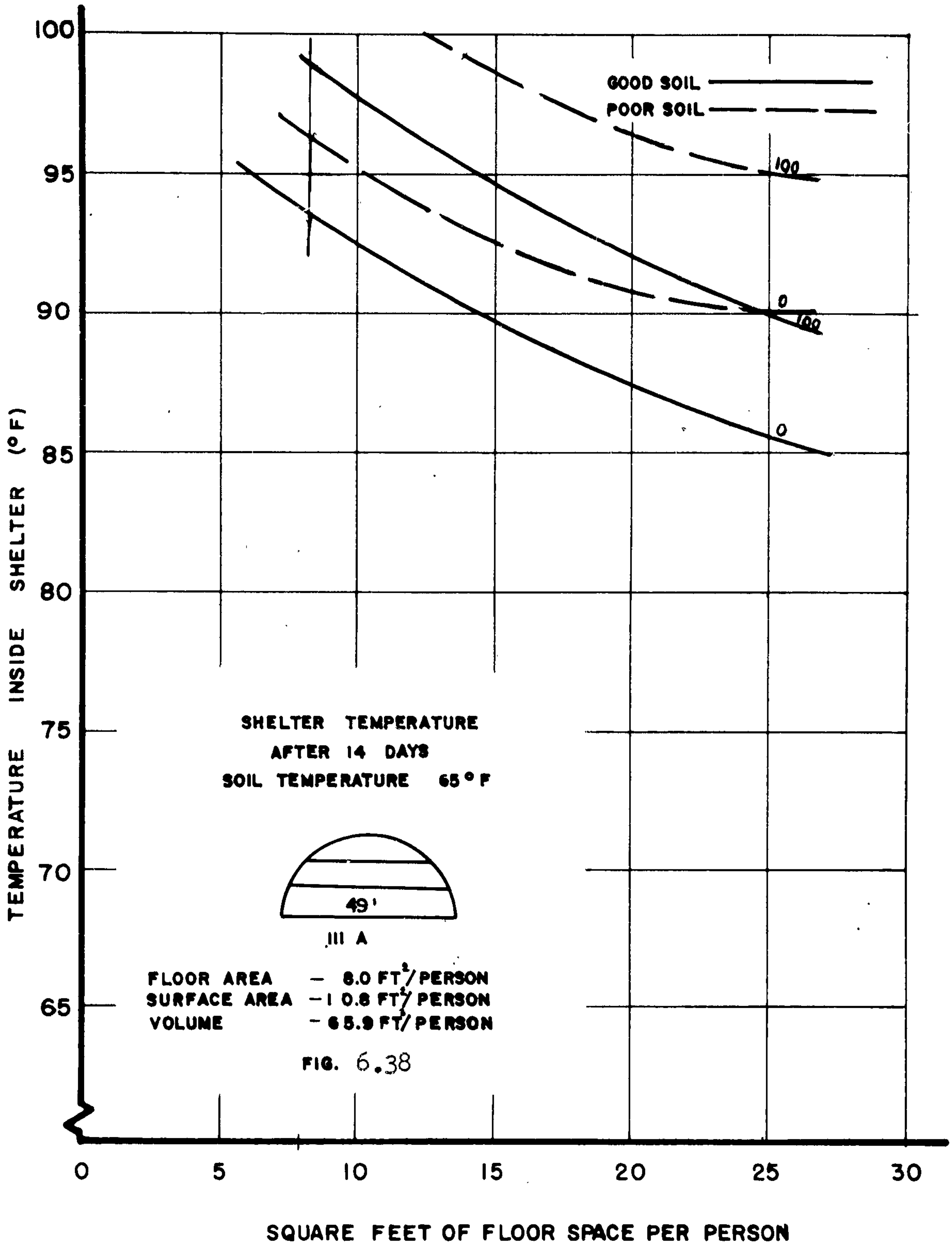

GOOD SOIL
POOR SOIL
100
0
100
0
TEMPERATURE INSIDE SHELTER (°F)
100
95
90
85
80
75
70
65
SHELTER TEMPERATURE
AFTER 14 DAYS
SOIL TEMPERATURE 65 °F
49'
III A
FLOOR AREA – 8.0 FT²/PERSON
SURFACE AREA – 10.8 FT²/PERSON
VOLUME – 65.9 FT³/PERSON
0
5
10
15
20
25
30
SQUARE FEET OF FLOOR SPACE PER PERSON

FIG. 6.38

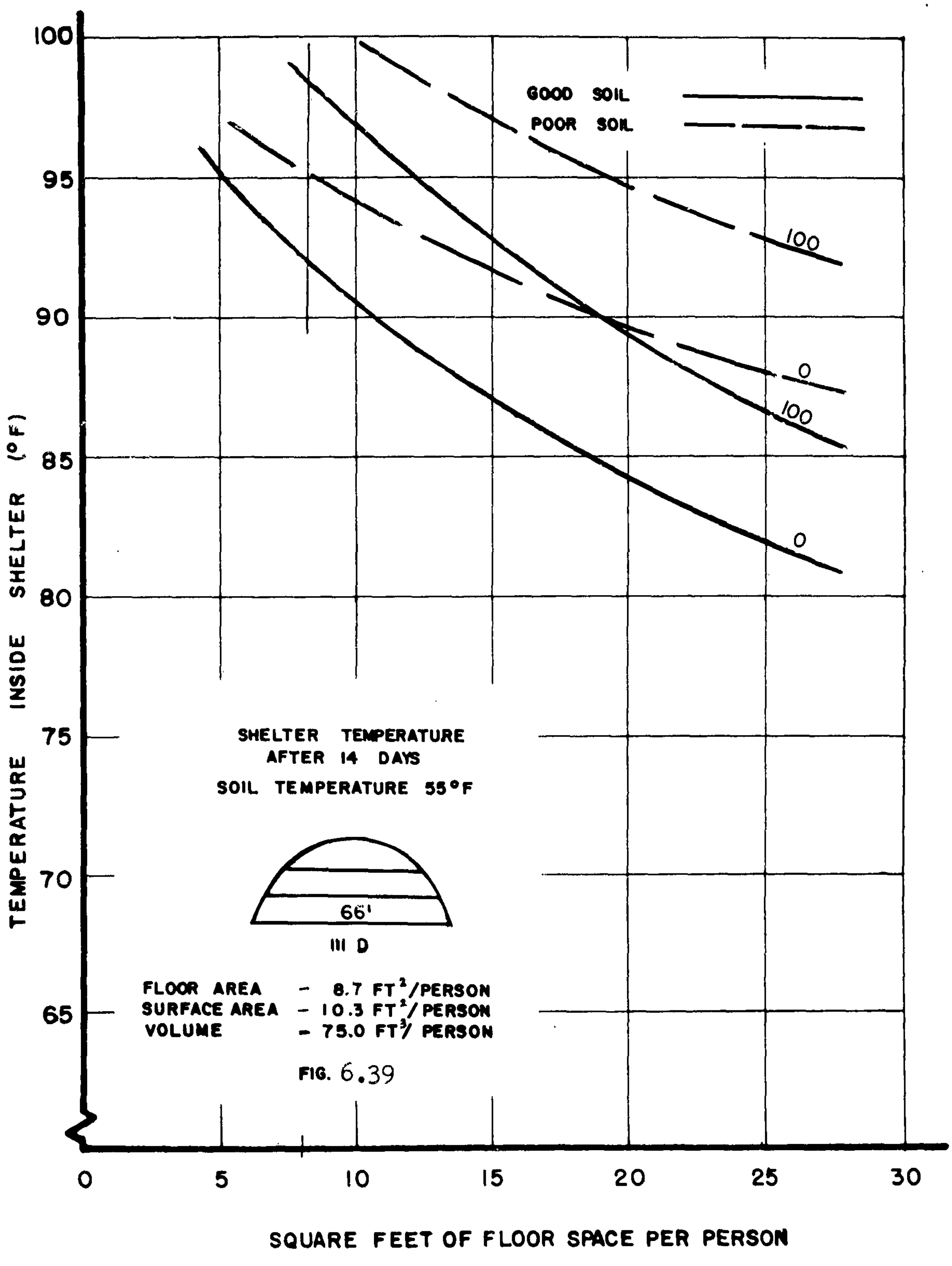

100
95
90
85
80
75
70
65
GOOD SOIL
POOR SOIL
100
0
100
0
TEMPERATURE INSIDE SHELTER (°F)
SHELTER TEMPERATURE
AFTER 14 DAYS
SOIL TEMPERATURE 55°F
66'
III D
FLOOR AREA - 8.7 FT²/PERSON
SURFACE AREA - 10.3 FT²/PERSON
VOLUME - 75.0 FT³/ PERSON
0
5
10
15
20
25
30
SQUARE FEET OF FLOOR SPACE PER PERSON

FIG. 6.39

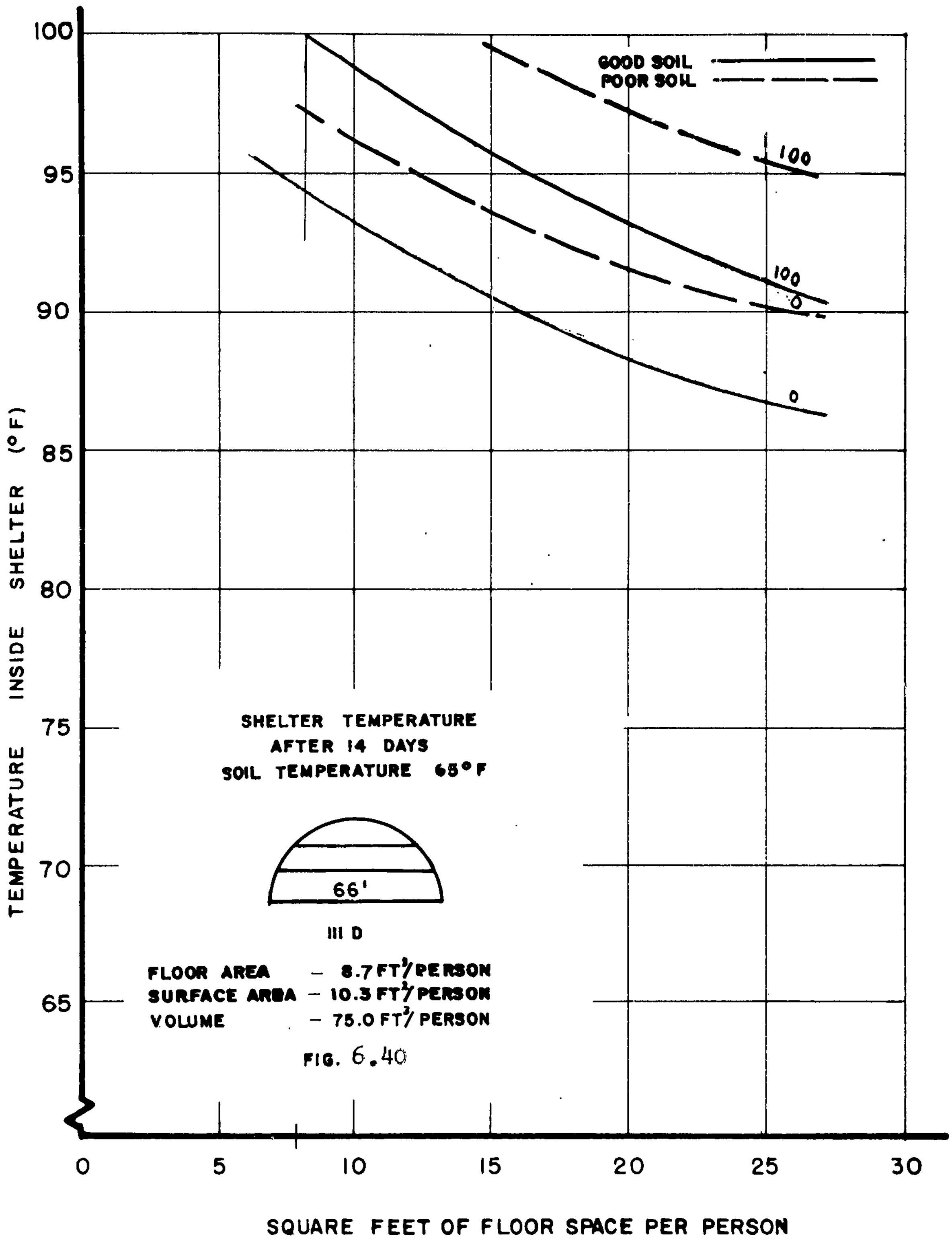

GOOD SOIL
POOR SOIL
100
100
0
0
100
95
90
85
80
75
70
65
TEMPERATURE INSIDE SHELTER (°F)
SHELTER TEMPERATURE
AFTER 14 DAYS
SOIL TEMPERATURE 65°F
66'
III D
FLOOR AREA – 8.7 FT²/PERSON
SURFACE AREA – 10.3 FT²/PERSON
VOLUME – 75.0 FT³/PERSON
0
5
10
15
20
25
30
SQUARE FEET OF FLOOR SPACE PER PERSON

FIG. 6.40

APPENDIX C-2

14-DAY HEAT TRANSFER

(AVERAGE TRANSFER RATES)

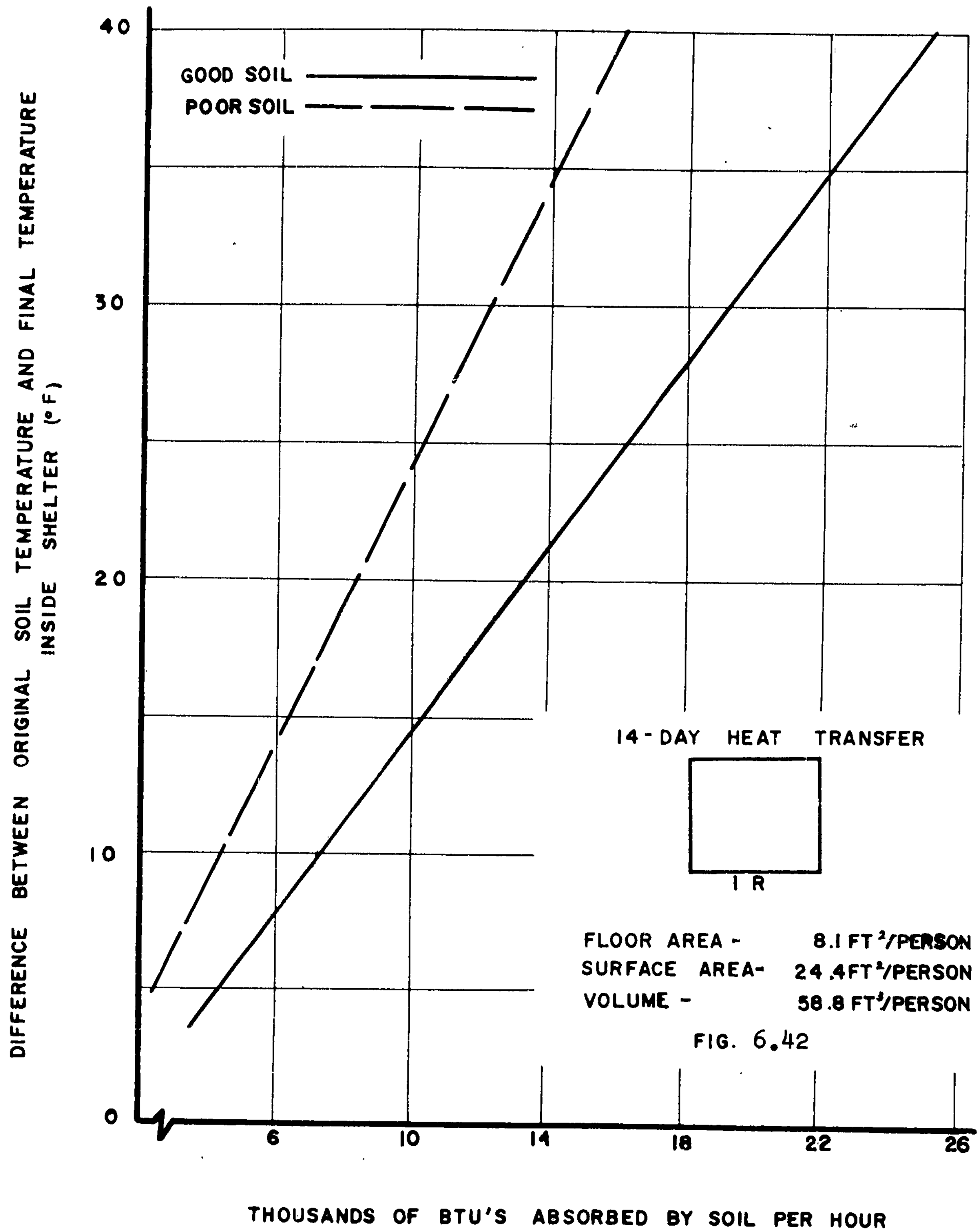

GOOD SOIL
POOR SOIL
DIFFERENCE BETWEEN ORIGINAL SOIL TEMPERATURE AND FINAL TEMPERATURE INSIDE SHELTER (°F)
0
10
20
30
40
6
10
14
18
22
26
THOUSANDS OF BTU'S ABSORBED BY SOIL PER HOUR
14-DAY HEAT TRANSFER
1 R
FLOOR AREA - 8.1 FT²/PERSON
SURFACE AREA - 24.4 FT²/PERSON
VOLUME - 58.8 FT³/PERSON

FIG. 6.42

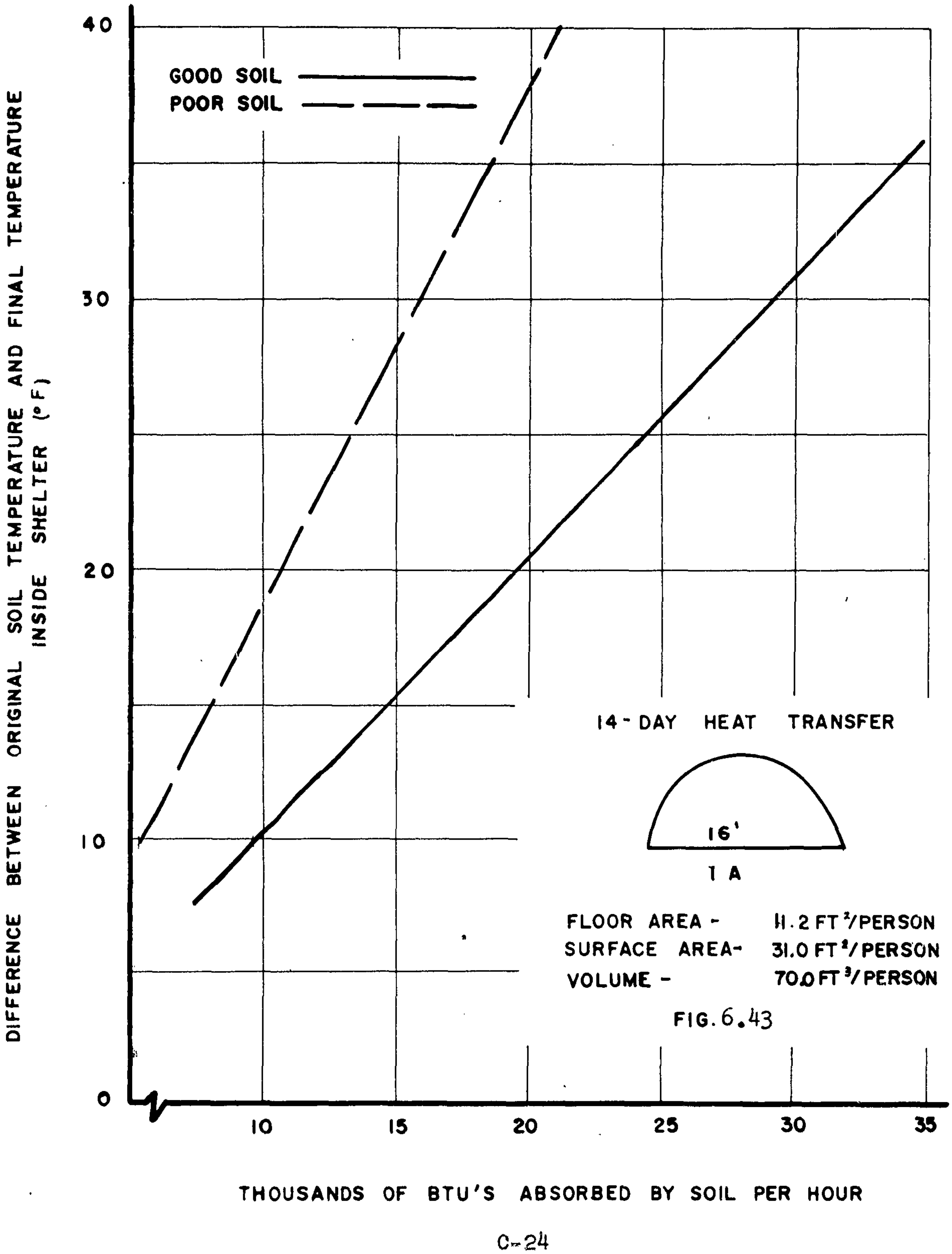
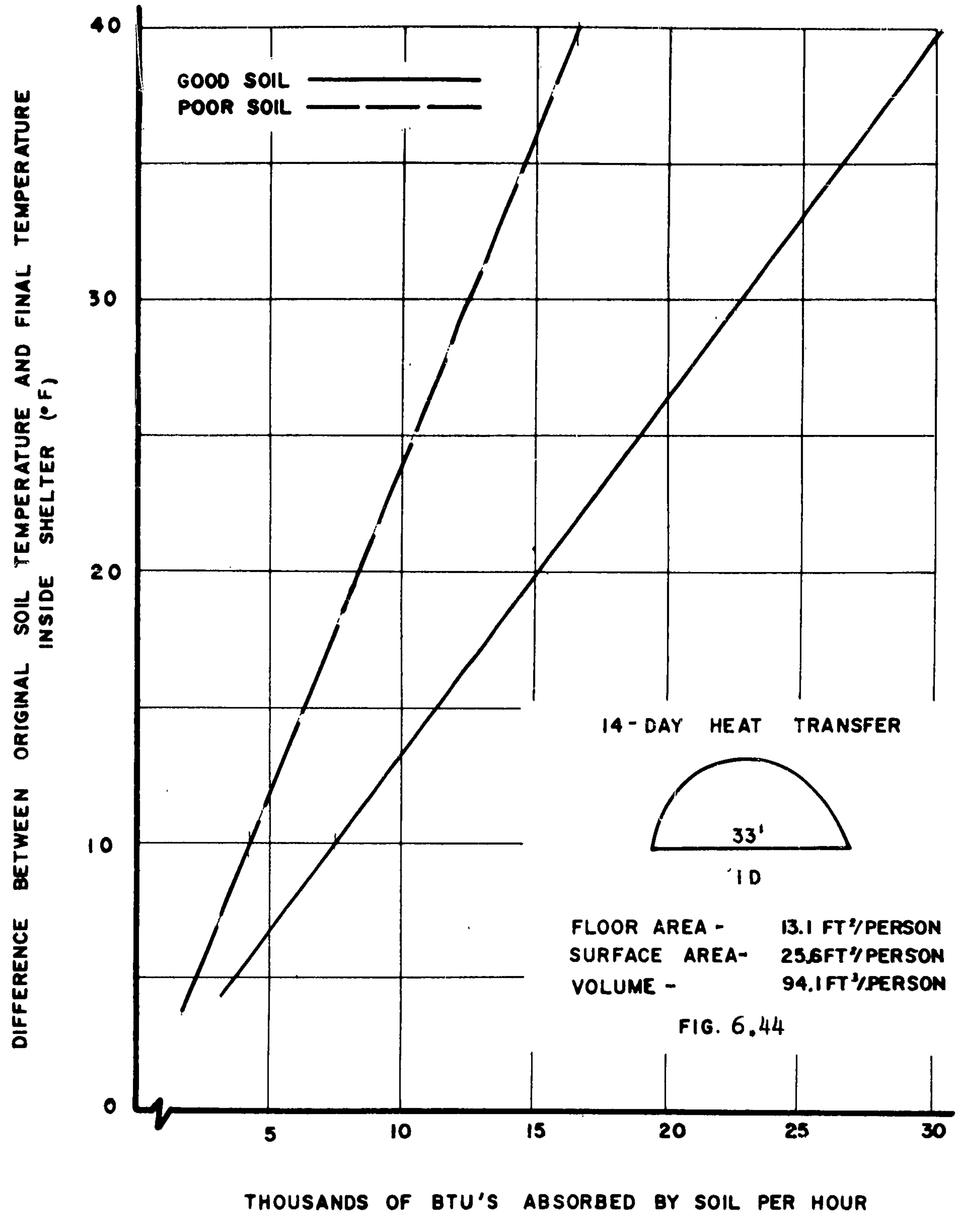

GOOD SOIL
POOR SOIL
DIFFERENCE BETWEEN ORIGINAL SOIL TEMPERATURE AND FINAL TEMPERATURE INSIDE SHELTER (°F)
40
30
20
10
0
10
15
20
25
30
35
THOUSANDS OF BTU'S ABSORBED BY SOIL PER HOUR
14 - DAY HEAT TRANSFER
16'
1 A
FLOOR AREA - 11.2 FT²/PERSON
SURFACE AREA - 31.0 FT²/PERSON
VOLUME - 70.0 FT³/PERSON

FIG. 6.43


GOOD SOIL
POOR SOIL
DIFFERENCE BETWEEN ORIGINAL SOIL TEMPERATURE AND FINAL TEMPERATURE INSIDE SHELTER (°F)
0
10
20
30
40
5
10
15
20
25
30
14-DAY HEAT TRANSFER
33'
ID
FLOOR AREA - 13.1 FT²/PERSON
SURFACE AREA- 25.6FT²/PERSON
VOLUME - 94.1 FT³/PERSON
THOUSANDS OF BTU'S ABSORBED BY SOIL PER HOUR
FIG. 6.44

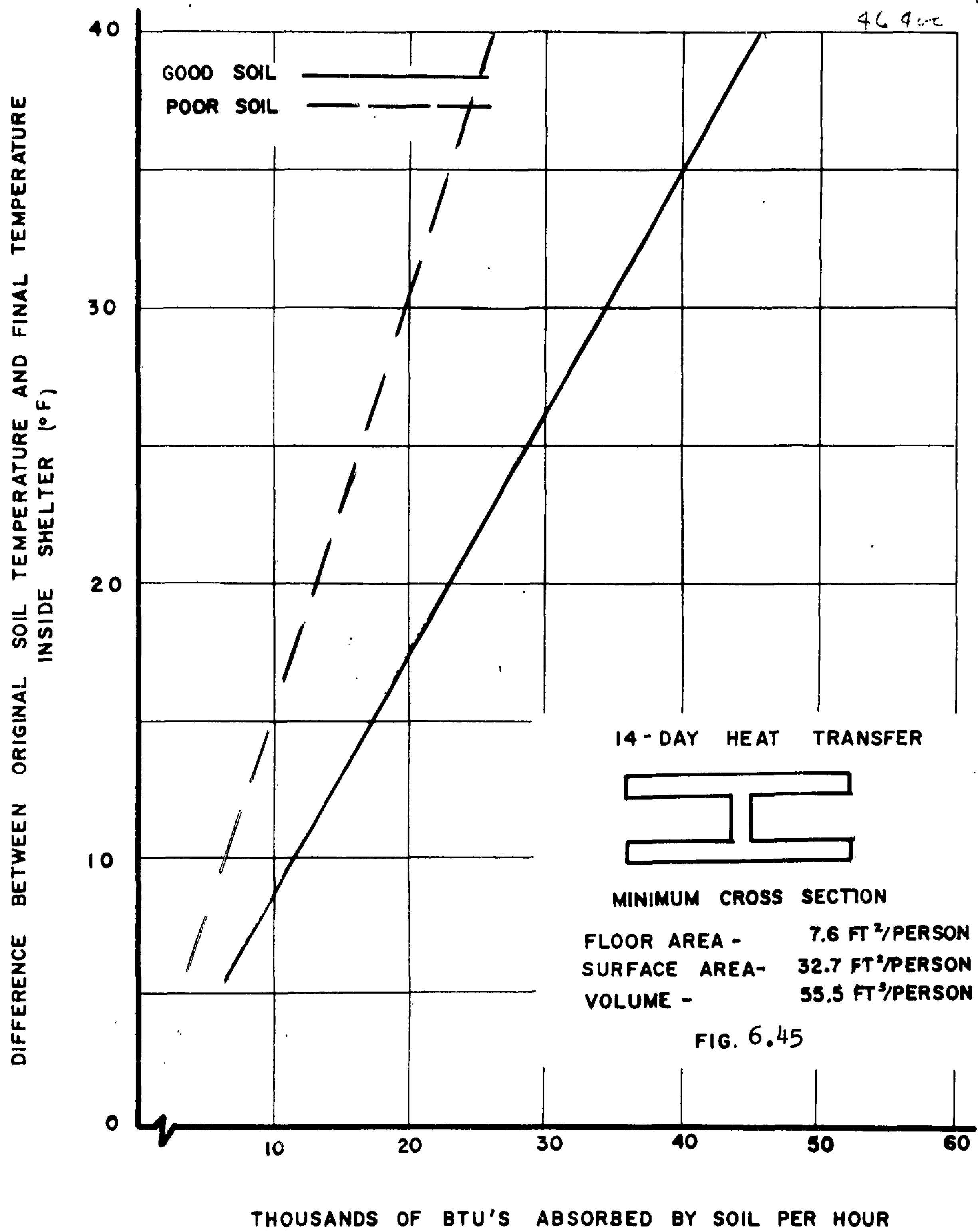

46 4-c
40
30
20
10
0
GOOD SOIL
POOR SOIL
DIFFERENCE BETWEEN ORIGINAL SOIL TEMPERATURE AND FINAL TEMPERATURE INSIDE SHELTER (°F)
14 - DAY HEAT TRANSFER
MINIMUM CROSS SECTION
FLOOR AREA - 7.6 FT²/PERSON
SURFACE AREA- 32.7 FT²/PERSON
VOLUME - 55.5 FT³/PERSON
10
20
30
40
50
60
THOUSANDS OF BTU'S ABSORBED BY SOIL PER HOUR

FIG. 6.45

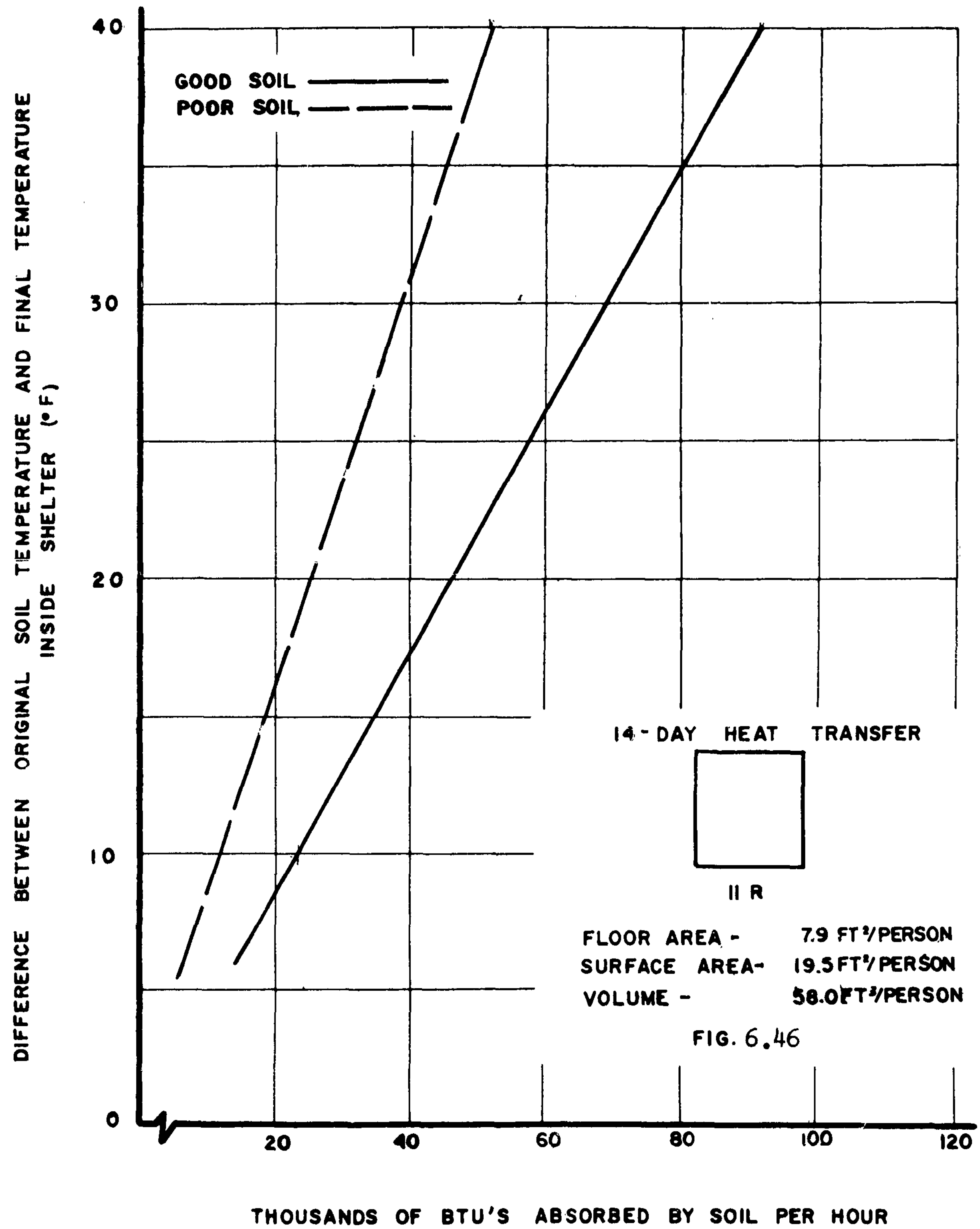
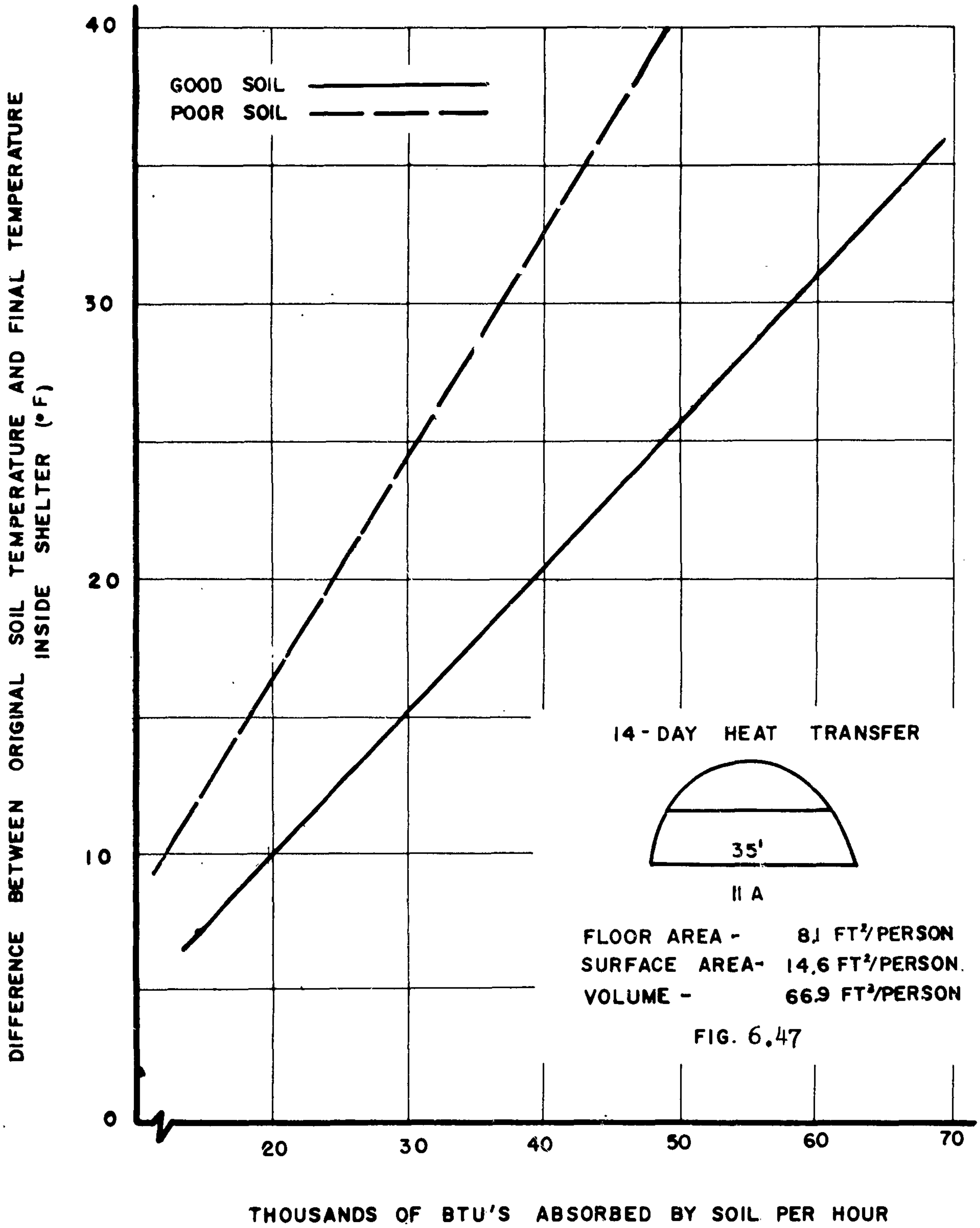
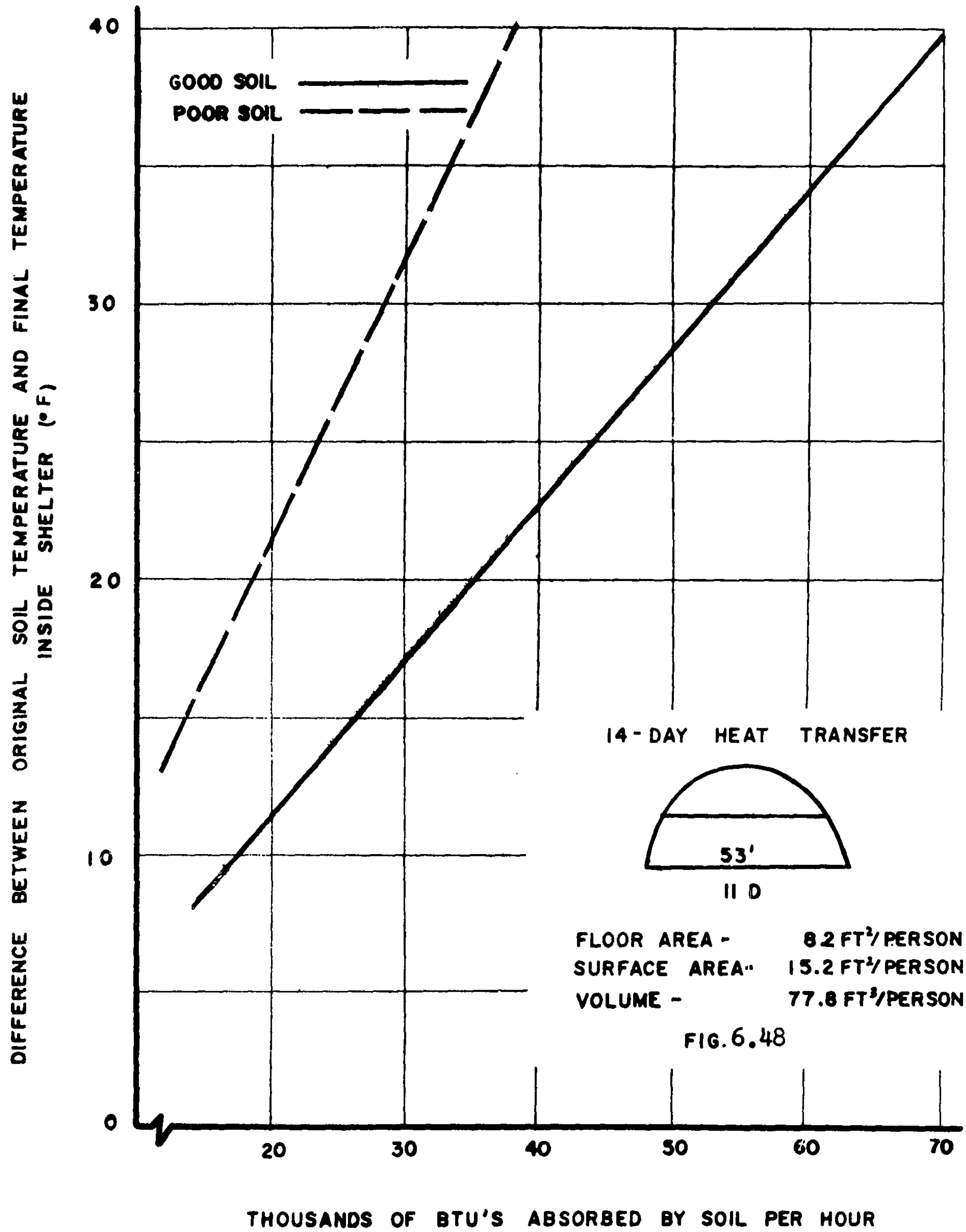

GOOD SOIL
POOR SOIL
DIFFERENCE BETWEEN ORIGINAL SOIL TEMPERATURE AND FINAL TEMPERATURE INSIDE SHELTER (°F)
40
30
20
10
0
20
40
60
80
100
120
THOUSANDS OF BTU'S ABSORBED BY SOIL PER HOUR
14 - DAY HEAT TRANSFER
11 R
FLOOR AREA - 7.9 FT²/PERSON
SURFACE AREA - 19.5 FT²/PERSON
VOLUME - 58.0 FT³/PERSON

FIG. 6.46



GOOD SOIL
POOR SOIL
40
30
20
10
0
20
30
40
50
60
70
DIFFERENCE BETWEEN ORIGINAL SOIL TEMPERATURE AND FINAL TEMPERATURE INSIDE SHELTER (°F)
THOUSANDS OF BTU'S ABSORBED BY SOIL PER HOUR
14-DAY HEAT TRANSFER
35'
II A
FLOOR AREA - 8.1 FT²/PERSON
SURFACE AREA- 14.6 FT²/PERSON.
VOLUME - 66.9 FT³/PERSON

FIG. 6.47



GOOD SOIL
POOR SOIL
DIFFERENCE BETWEEN ORIGINAL SOIL TEMPERATURE AND FINAL TEMPERATURE INSIDE SHELTER (°F)
0
10
20
30
40
20
30
40
50
60
70
THOUSANDS OF BTU'S ABSORBED BY SOIL PER HOUR
14 - DAY HEAT TRANSFER
53'
II D
FLOOR AREA - 8.2 FT²/PERSON
SURFACE AREA - 15.2 FT²/PERSON
VOLUME - 77.8 FT³/PERSON

FIG. 6.48

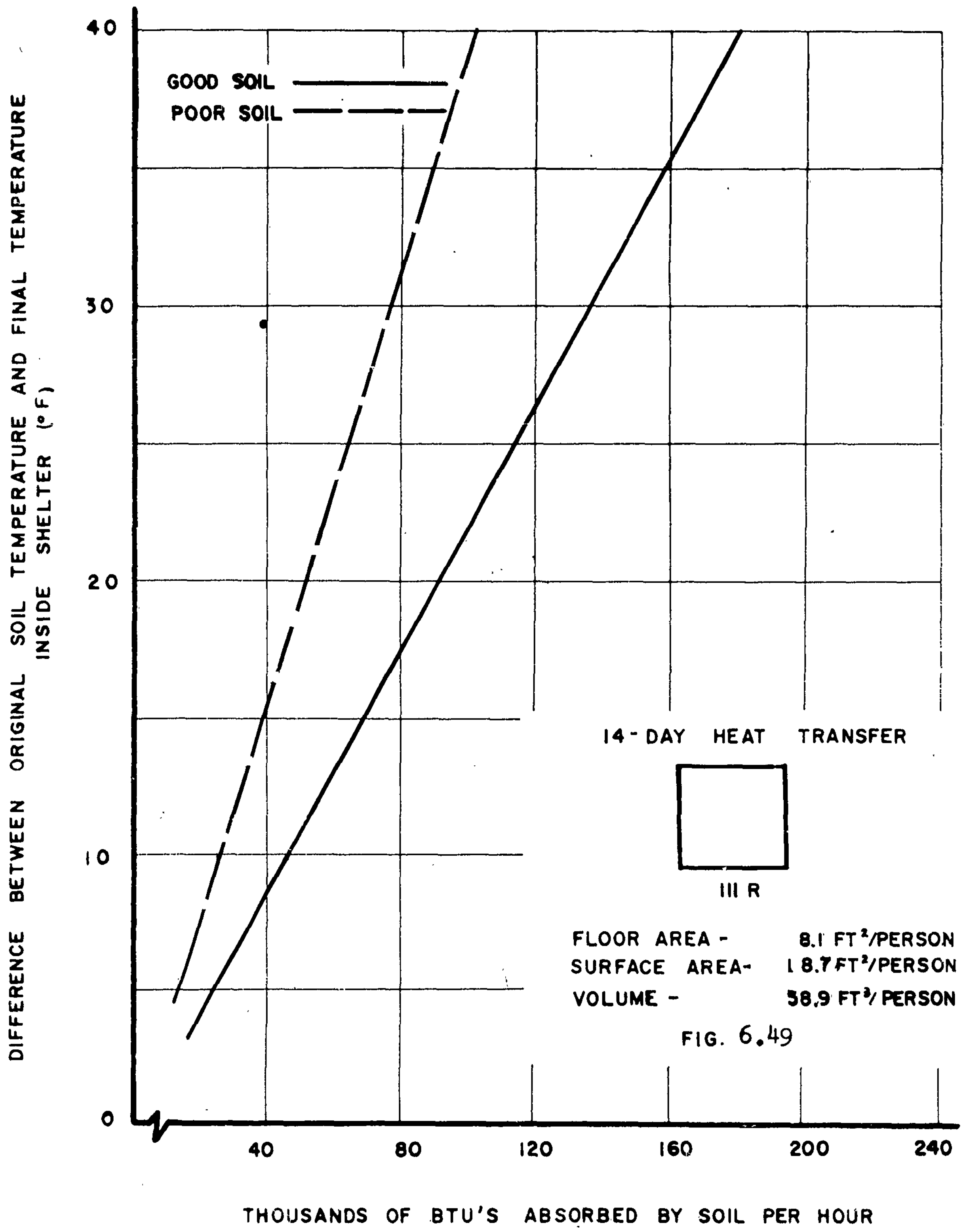

DIFFERENCE BETWEEN ORIGINAL SOIL TEMPERATURE AND FINAL TEMPERATURE INSIDE SHELTER (°F)
0
10
20
30
40
GOOD SOIL
POOR SOIL
14 - DAY HEAT TRANSFER
III R
FLOOR AREA - 8.1 FT²/PERSON
SURFACE AREA - 18.7 FT²/PERSON
VOLUME - 58.9 FT³/PERSON
40
80
120
160
200
240
THOUSANDS OF BTU'S ABSORBED BY SOIL PER HOUR

FIG. 6.49

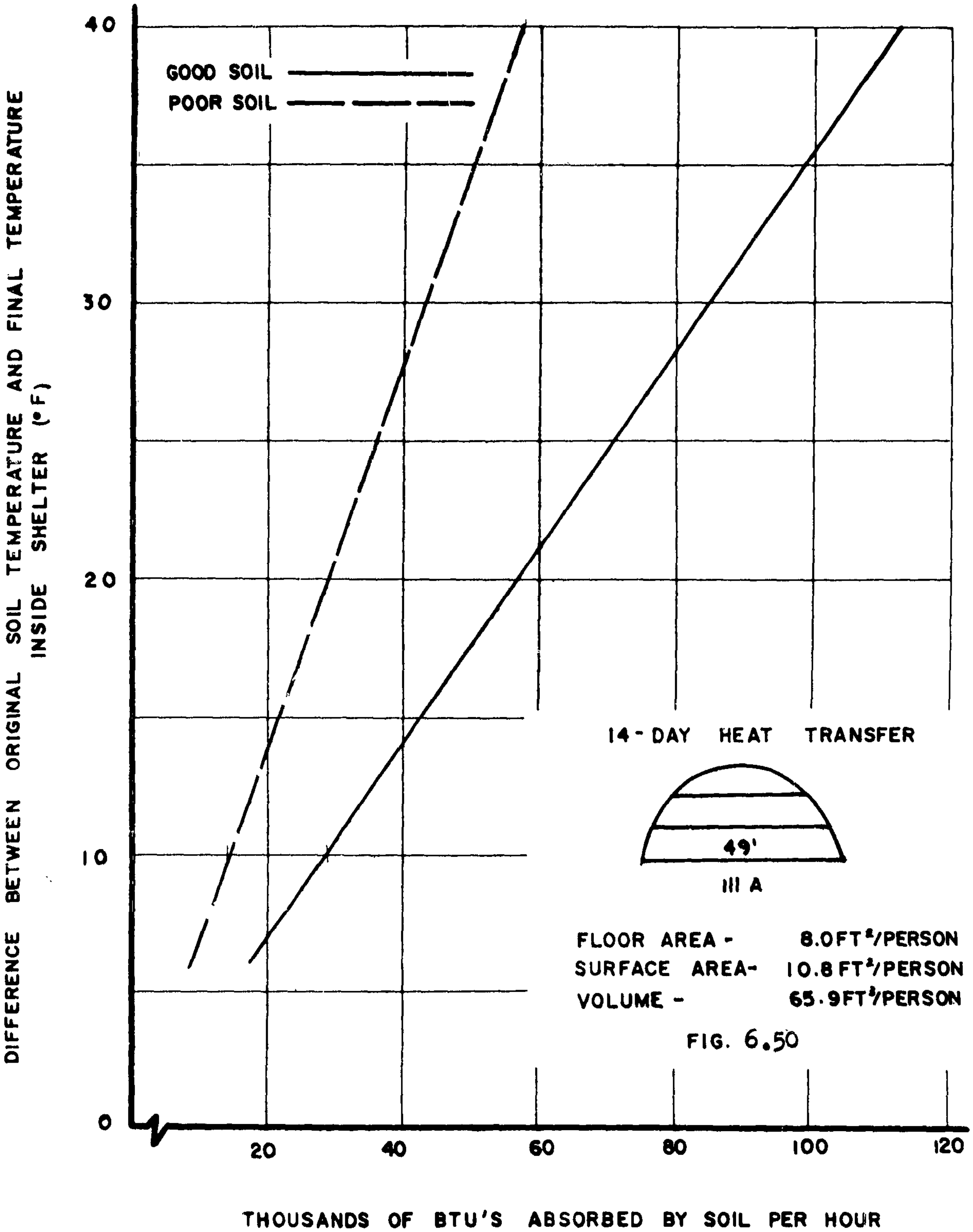

GOOD SOIL
POOR SOIL
DIFFERENCE BETWEEN ORIGINAL SOIL TEMPERATURE AND FINAL TEMPERATURE INSIDE SHELTER (°F)
40
30
20
10
0
20
40
60
80
100
120
THOUSANDS OF BTU'S ABSORBED BY SOIL PER HOUR
14 - DAY HEAT TRANSFER
49'
III A
FLOOR AREA - 8.0FT²/PERSON
SURFACE AREA- 10.8FT²/PERSON
VOLUME - 65.9FT³/PERSON

FIG. 6.50

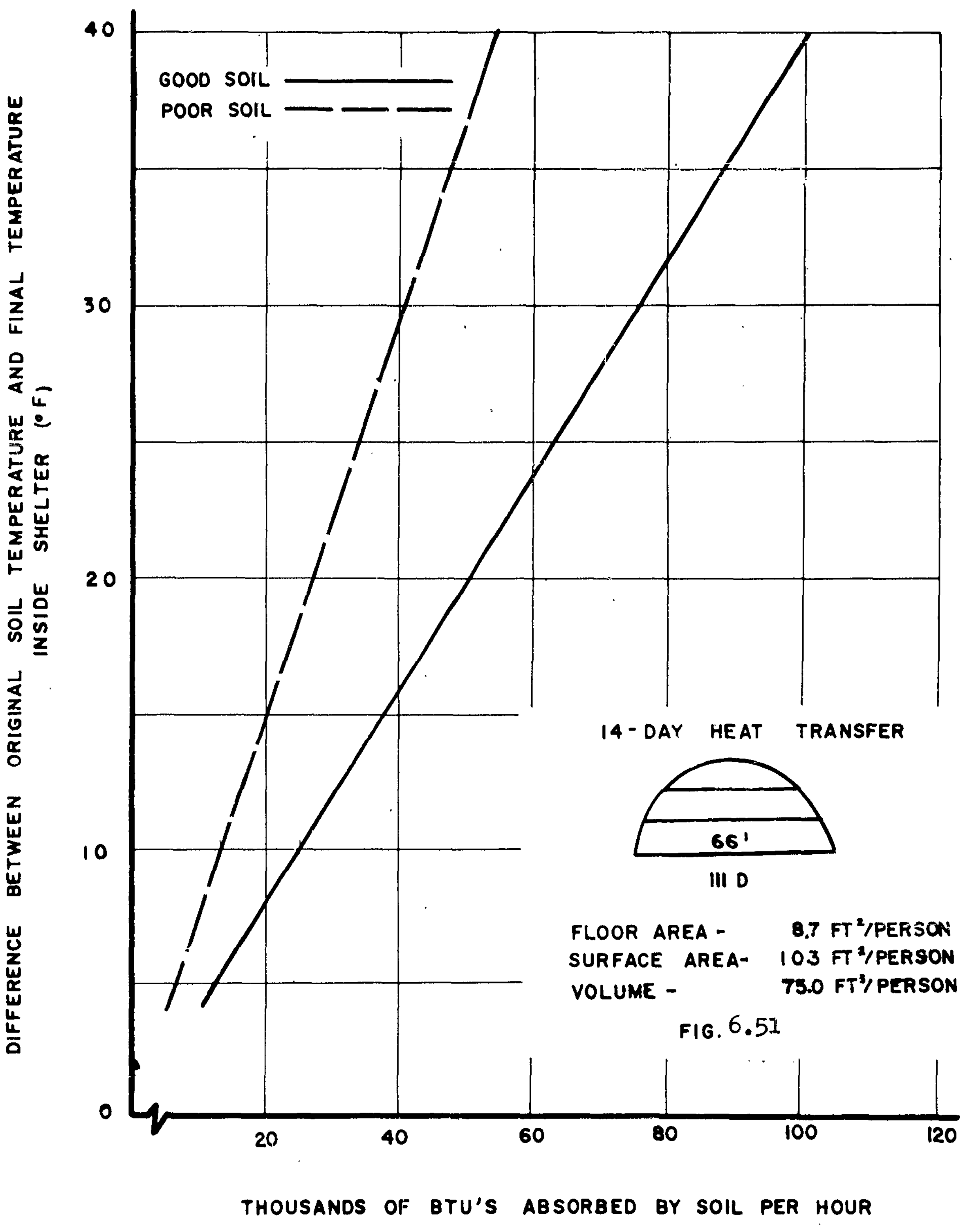

GOOD SOIL
POOR SOIL
40
30
20
10
0
20
40
60
80
100
120
DIFFERENCE BETWEEN ORIGINAL SOIL TEMPERATURE AND FINAL TEMPERATURE INSIDE SHELTER (°F)
THOUSANDS OF BTU'S ABSORBED BY SOIL PER HOUR
14-DAY HEAT TRANSFER
66'
III D
FLOOR AREA - 8.7 FT²/PERSON
SURFACE AREA- 103 FT²/PERSON
VOLUME - 75.0 FT³/PERSON

FIG. 6.51

APPENDIX C-3

14-DAY HEAT TRANSFER

(NUMERICAL SOLUTION)

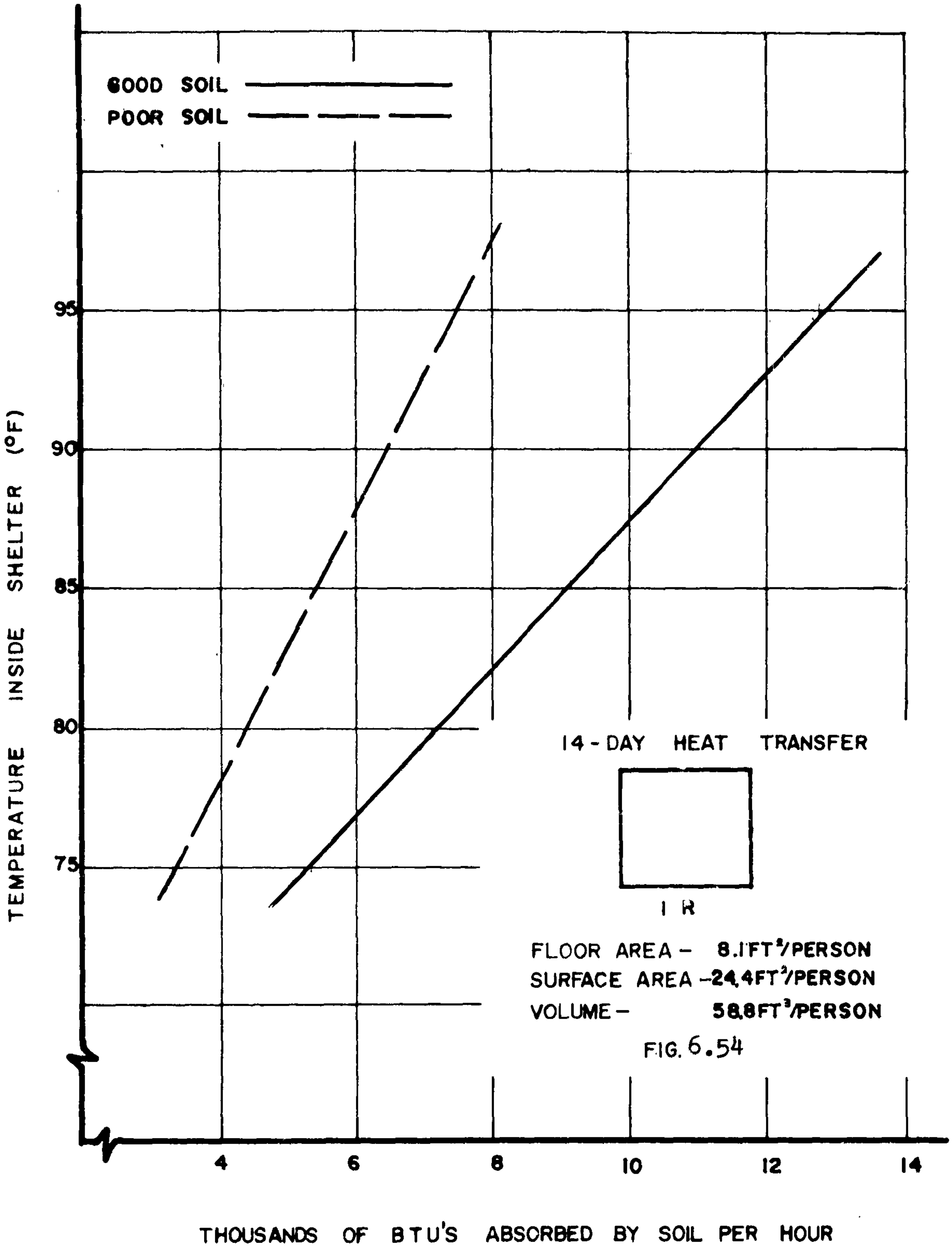
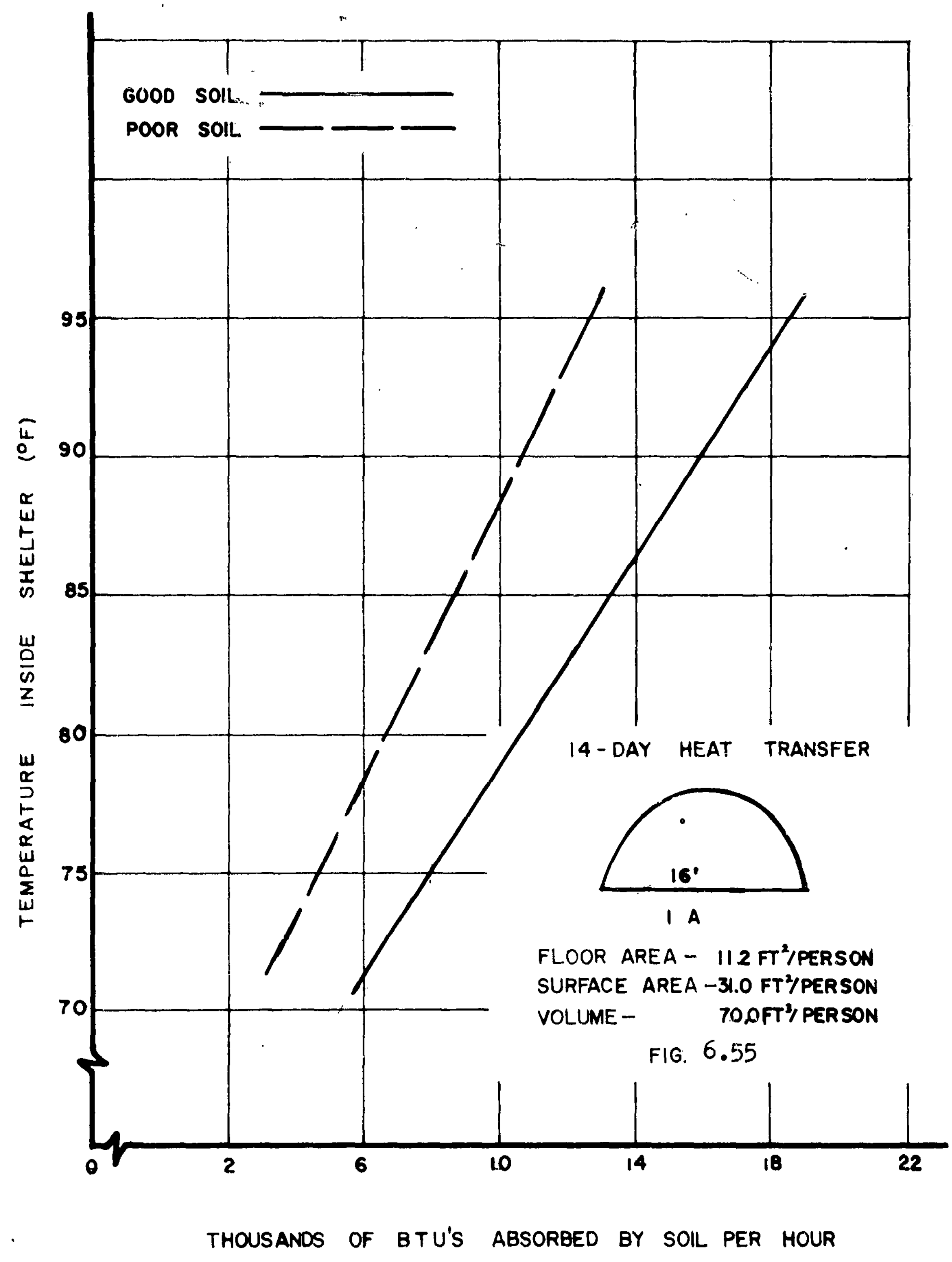

GOOD SOIL
POOR SOIL
TEMPERATURE INSIDE SHELTER (°F)
95
90
85
80
75
4
6
8
10
12
14
14 - DAY HEAT TRANSFER
1 R
FLOOR AREA - 8.1FT²/PERSON
SURFACE AREA - 24.4FT²/PERSON
VOLUME - 58.8FT³/PERSON
THOUSANDS OF BTU'S ABSORBED BY SOIL PER HOUR

FIG. 6.54



GOOD SOIL
POOR SOIL
95
90
85
80
75
70
TEMPERATURE INSIDE SHELTER (°F)
14 - DAY HEAT TRANSFER
16'
I A
FLOOR AREA - 11.2 FT²/PERSON
SURFACE AREA - 31.0 FT²/PERSON
VOLUME - 70.0 FT³/PERSON
0
2
6
10
14
18
22
THOUSANDS OF BTU'S ABSORBED BY SOIL PER HOUR

FIG. 6.55

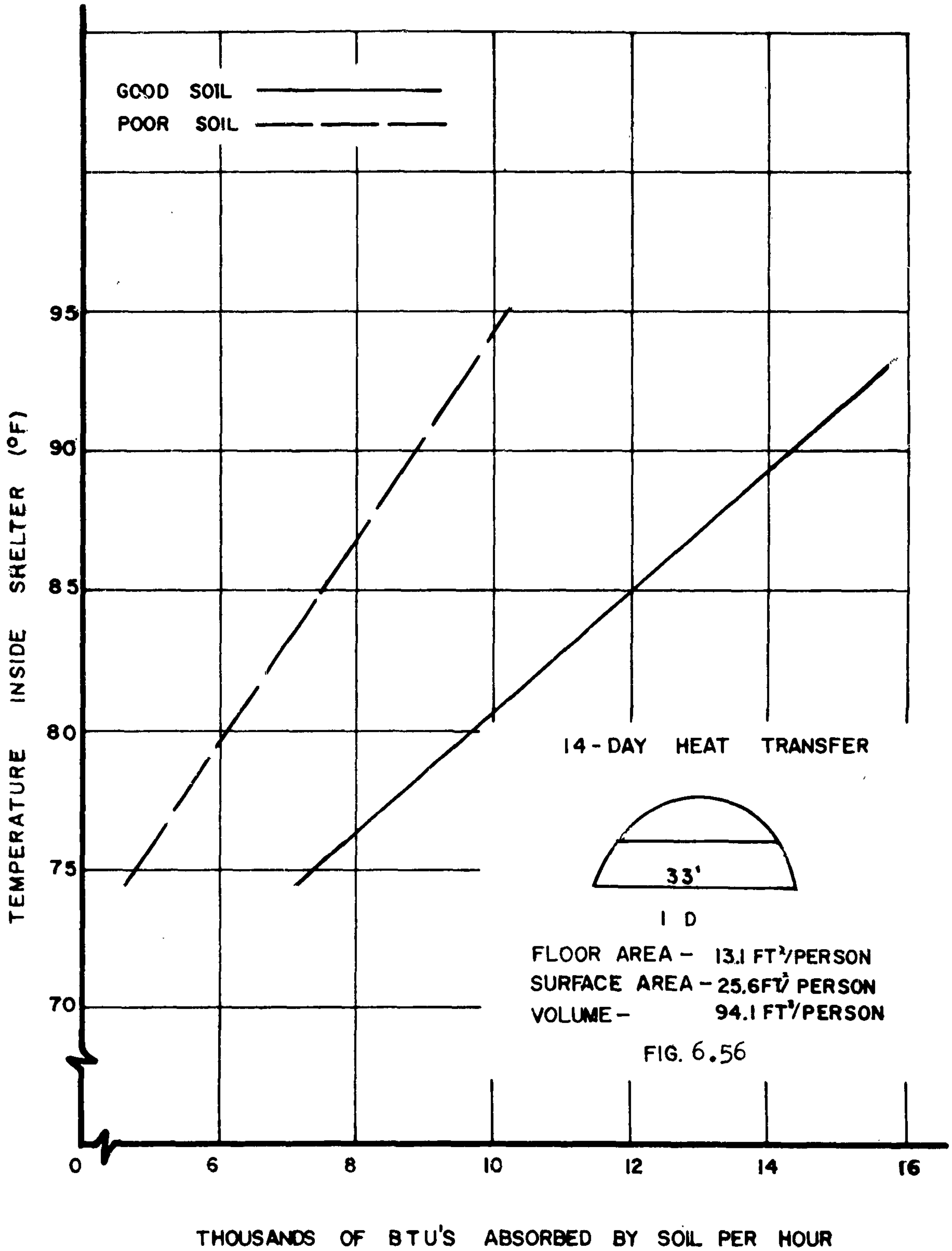

GOOD SOIL
POOR SOIL
TEMPERATURE INSIDE SHELTER (°F)
95
90
85
80
75
70
0
6
8
10
12
14
16
THOUSANDS OF BTU'S ABSORBED BY SOIL PER HOUR
14 - DAY HEAT TRANSFER
33'
I D
FLOOR AREA - 13.1 FT²/PERSON
SURFACE AREA - 25.6FT²/ PERSON
VOLUME - 94.1 FT³/PERSON

FIG. 6.56

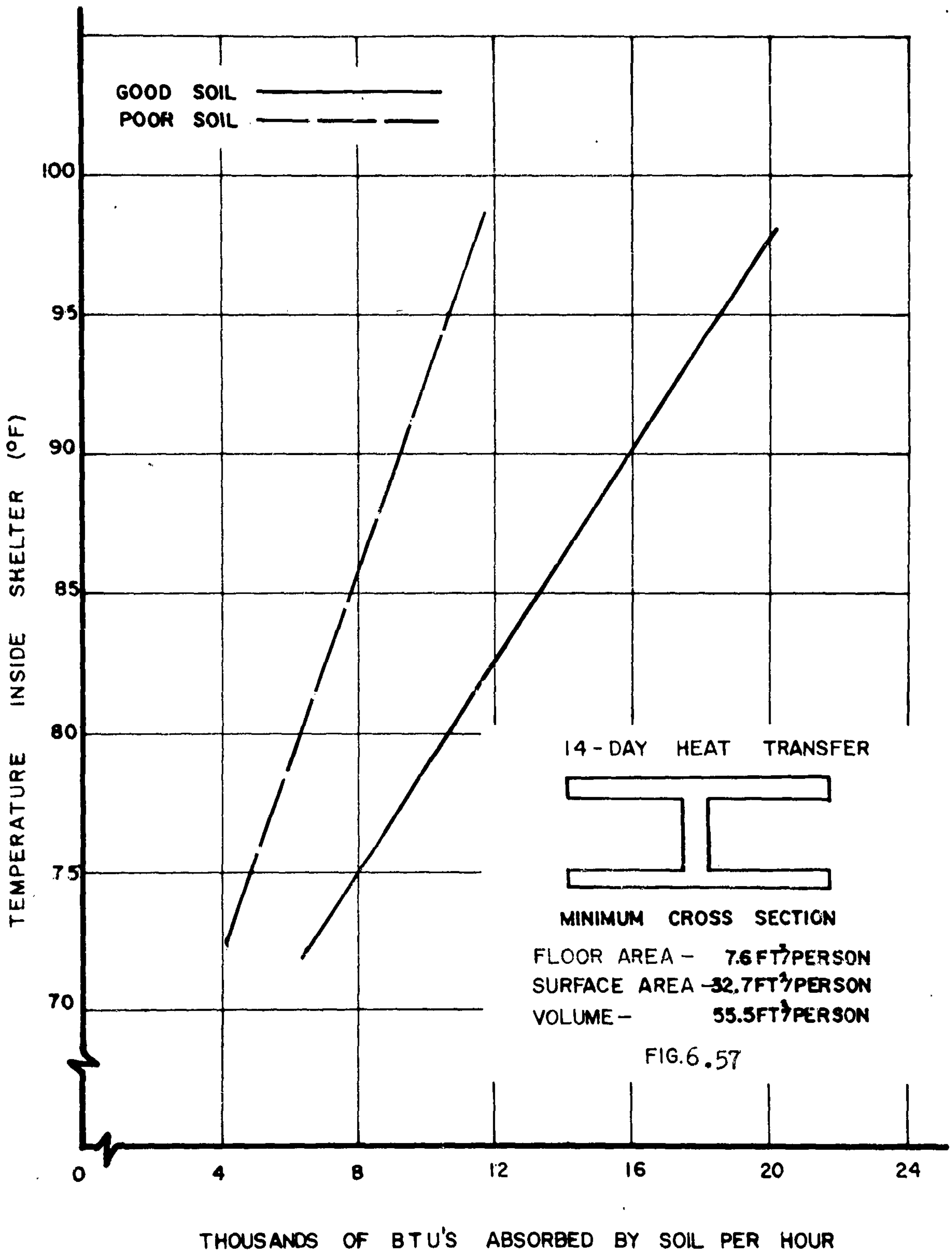

GOOD SOIL
POOR SOIL
100
95
90
85
80
75
70
TEMPERATURE INSIDE SHELTER (°F)
0
4
8
12
16
20
24
THOUSANDS OF BTU'S ABSORBED BY SOIL PER HOUR
14-DAY HEAT TRANSFER
MINIMUM CROSS SECTION
FLOOR AREA - 7.6 FT²/PERSON
SURFACE AREA - 32.7 FT²/PERSON
VOLUME - 55.5 FT³/PERSON

FIG. 6.57

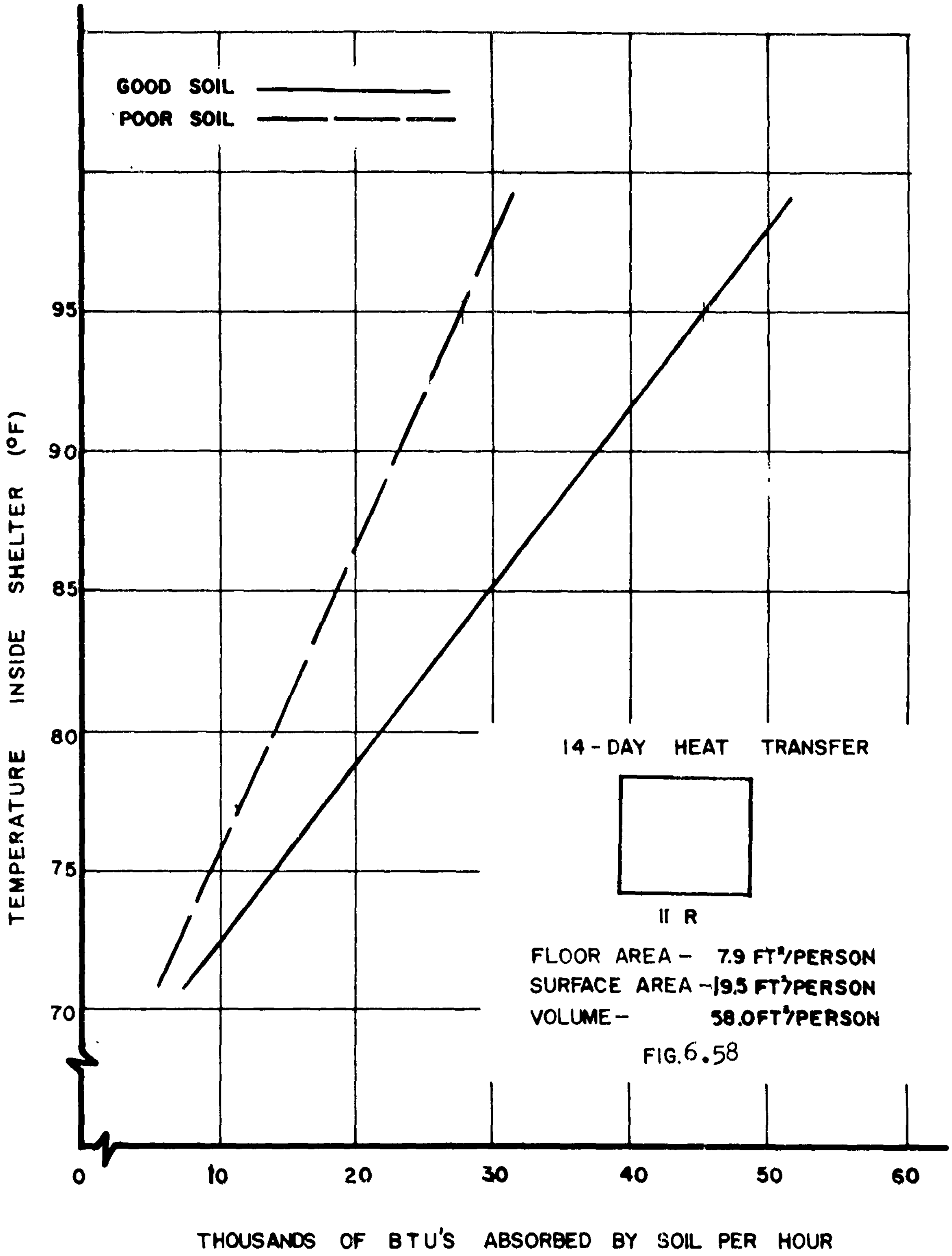

GOOD SOIL
POOR SOIL
TEMPERATURE INSIDE SHELTER (°F)
95
90
85
80
75
70
0
10
20
30
40
50
60
THOUSANDS OF BTU'S ABSORBED BY SOIL PER HOUR
14 - DAY HEAT TRANSFER
11 R
FLOOR AREA - 7.9 FT²/PERSON
SURFACE AREA - 19.5 FT²/PERSON
VOLUME - 58.0 FT³/PERSON

FIG. 6.58

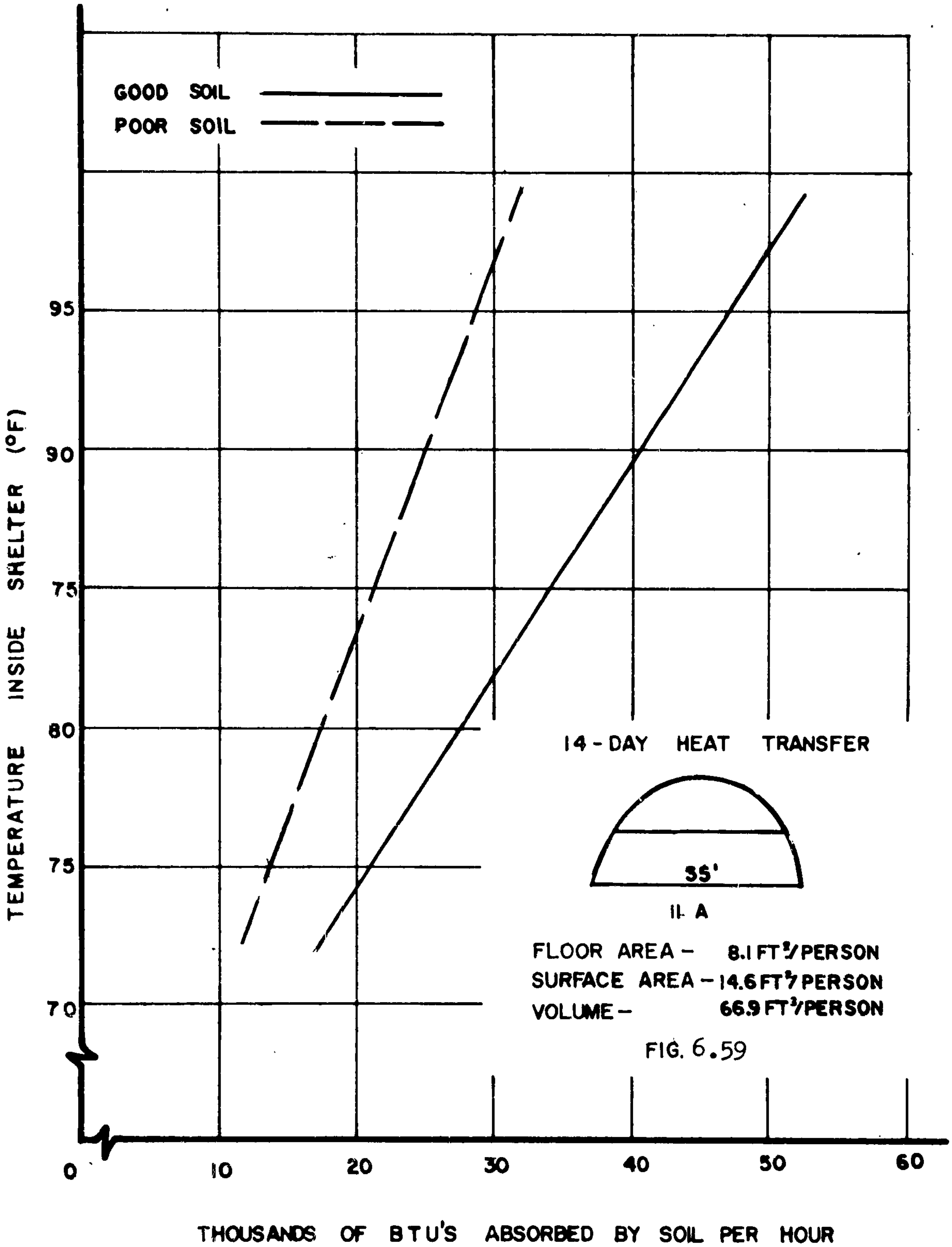

GOOD SOIL
POOR SOIL
TEMPERATURE INSIDE SHELTER (°F)
95
90
75
80
75
70
0
10
20
30
40
50
60
THOUSANDS OF BTU'S ABSORBED BY SOIL PER HOUR
14 - DAY HEAT TRANSFER
35'
II- A
FLOOR AREA - 8.1 FT²/PERSON
SURFACE AREA - 14.6 FT²/PERSON
VOLUME - 66.9 FT³/PERSON

FIG. 6.59

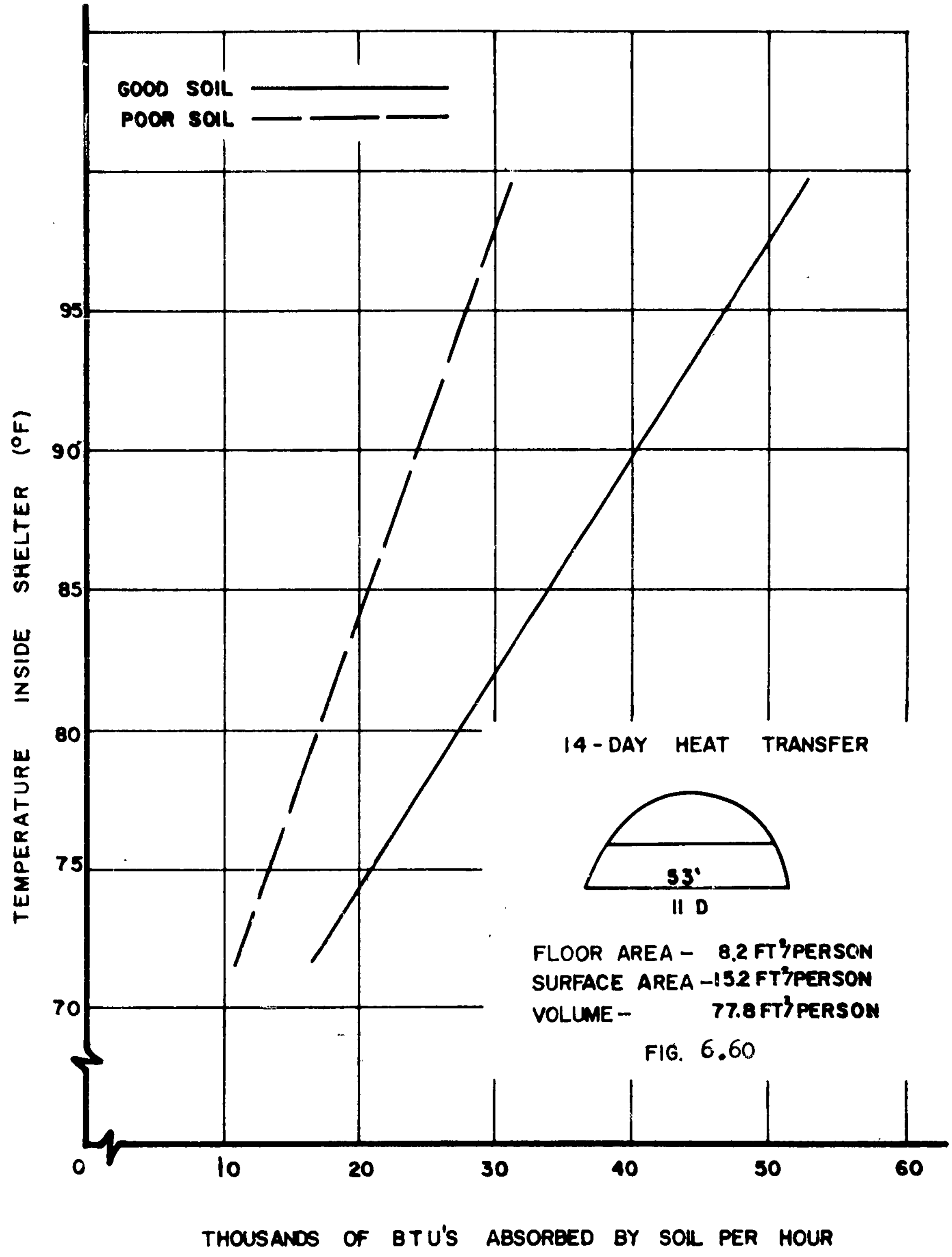
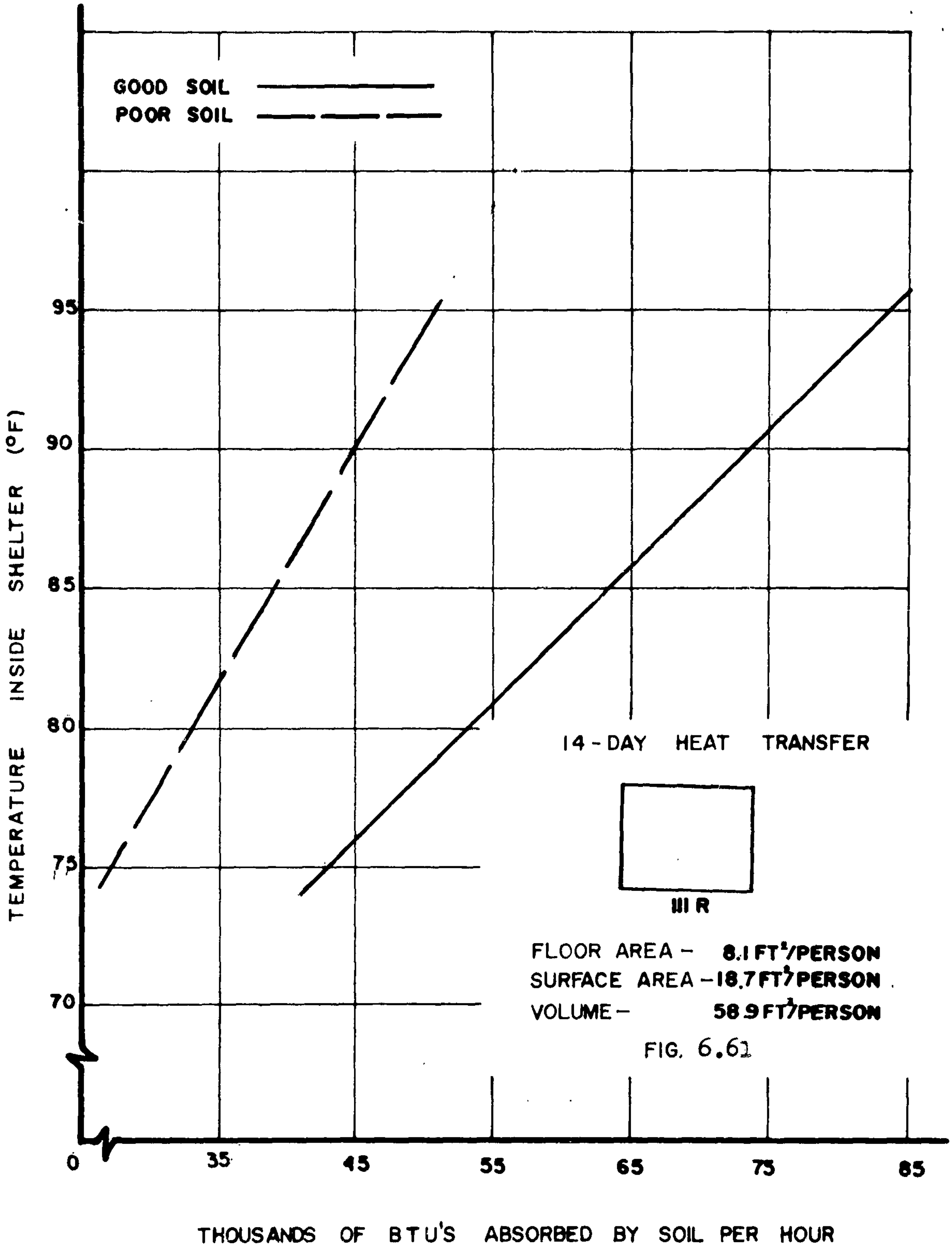

GOOD SOIL
POOR SOIL
TEMPERATURE INSIDE SHELTER (°F)
70
75
80
85
90
95
0
10
20
30
40
50
60
THOUSANDS OF BTU'S ABSORBED BY SOIL PER HOUR
14 - DAY HEAT TRANSFER
53'
11 D
FLOOR AREA – 8.2 FT²/PERSON
SURFACE AREA – 15.2 FT²/PERSON
VOLUME – 77.8 FT³/PERSON

FIG. 6.60



GOOD SOIL
POOR SOIL
95
90
85
80
75
70
0
35
45
55
65
75
85
TEMPERATURE INSIDE SHELTER (°F)
THOUSANDS OF BTU'S ABSORBED BY SOIL PER HOUR
14 - DAY HEAT TRANSFER
III R
FLOOR AREA - 8.1 FT²/PERSON
SURFACE AREA - 18.7 FT²/PERSON
VOLUME - 58.9 FT³/PERSON

FIG. 6.61

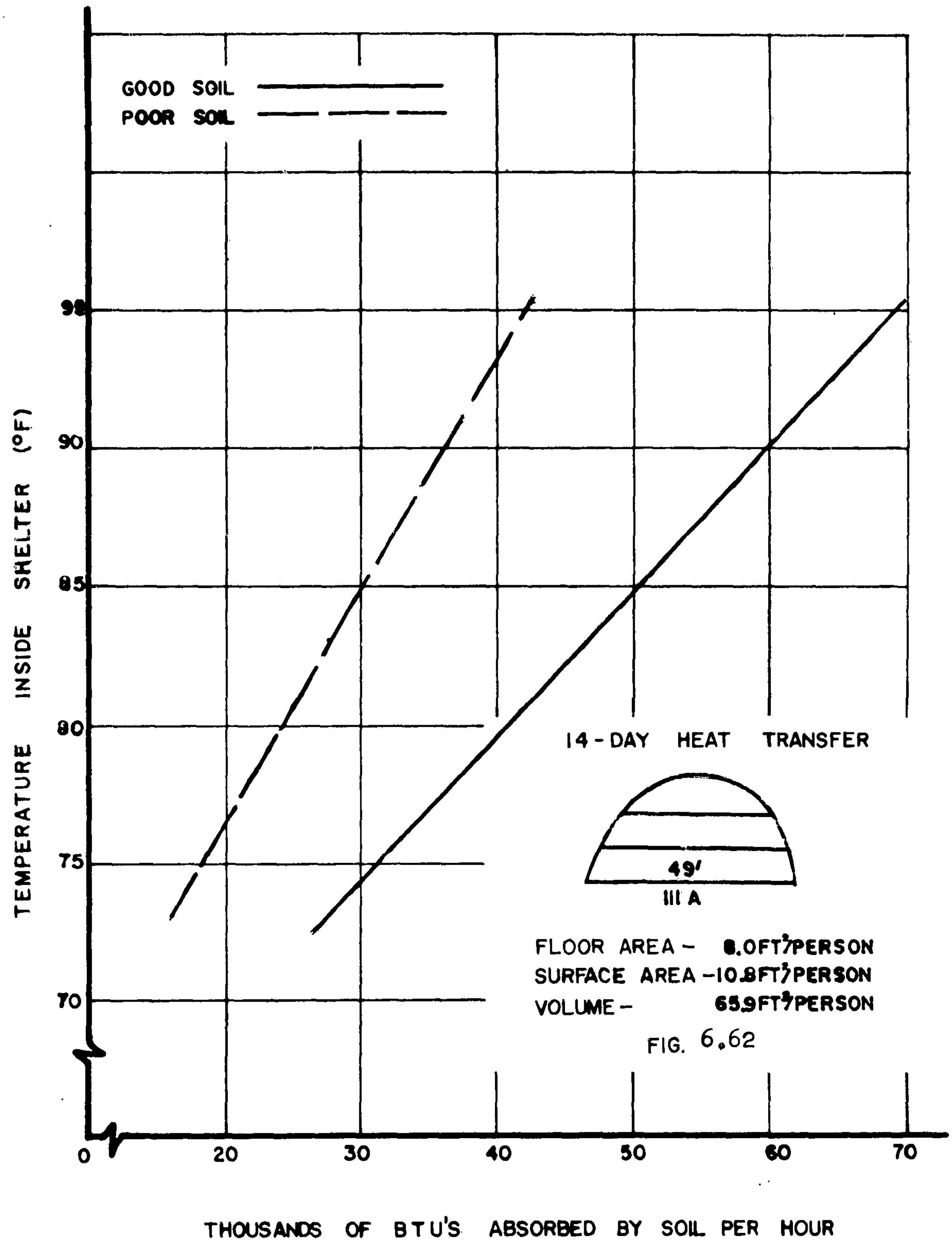
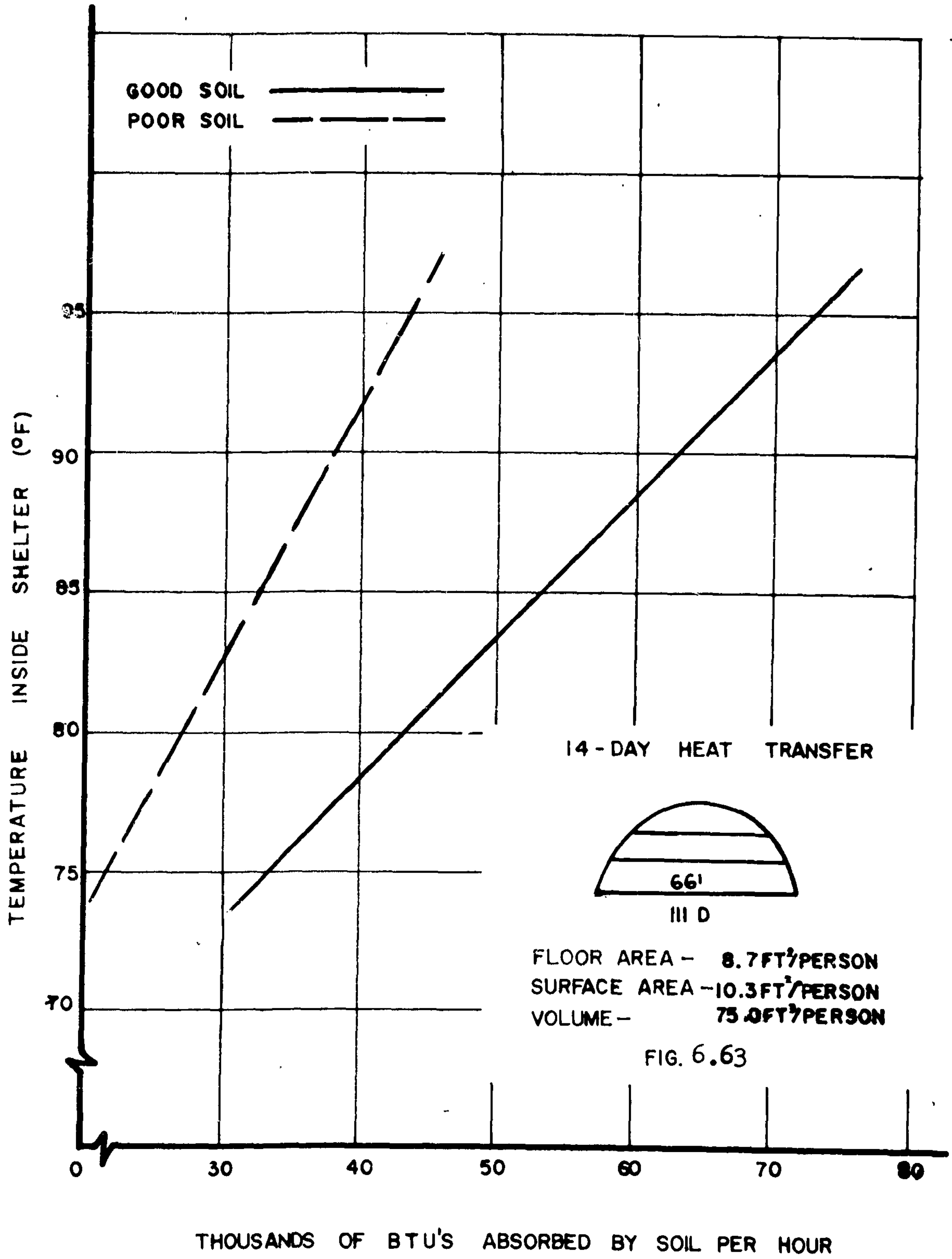

GOOD SOIL
POOR SOIL
TEMPERATURE INSIDE SHELTER (°F)
95
90
85
80
75
70
0
20
30
40
50
60
70
14-DAY HEAT TRANSFER
49'
III A
FLOOR AREA - 8.0FT²/PERSON
SURFACE AREA - 10.8FT²/PERSON
VOLUME - 65.9FT³/PERSON
THOUSANDS OF BTU'S ABSORBED BY SOIL PER HOUR

FIG. 6.62



GOOD SOIL
POOR SOIL
TEMPERATURE INSIDE SHELTER (°F)
95
90
85
80
75
70
0
30
40
50
60
70
80
THOUSANDS OF BTU'S ABSORBED BY SOIL PER HOUR
14 - DAY HEAT TRANSFER
66'
III D
FLOOR AREA - 8.7 FT²/PERSON
SURFACE AREA - 10.3 FT²/PERSON
VOLUME - 75.0 FT³/PERSON

FIG. 6.63